U.S. DEPARTMENT OF COMMERCE
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PB-300 536

Groundwater Quality Monitoring of Western Oil Shale Development: Identification and Priority Ranking of Potential Pollution Sources

General Electric Co., Santa Barbara, CA

Prepared for

Environmental Monitoring and Support Lab., Las Vegas, NV

Jun 79

United States
Environmental Protection
Agency

Environmental Monitoring
and Support Laboratory
P.O. Box 15027
Las Vegas NV 89114

EPA-600/7-79-023
January, 1979

Research and Development

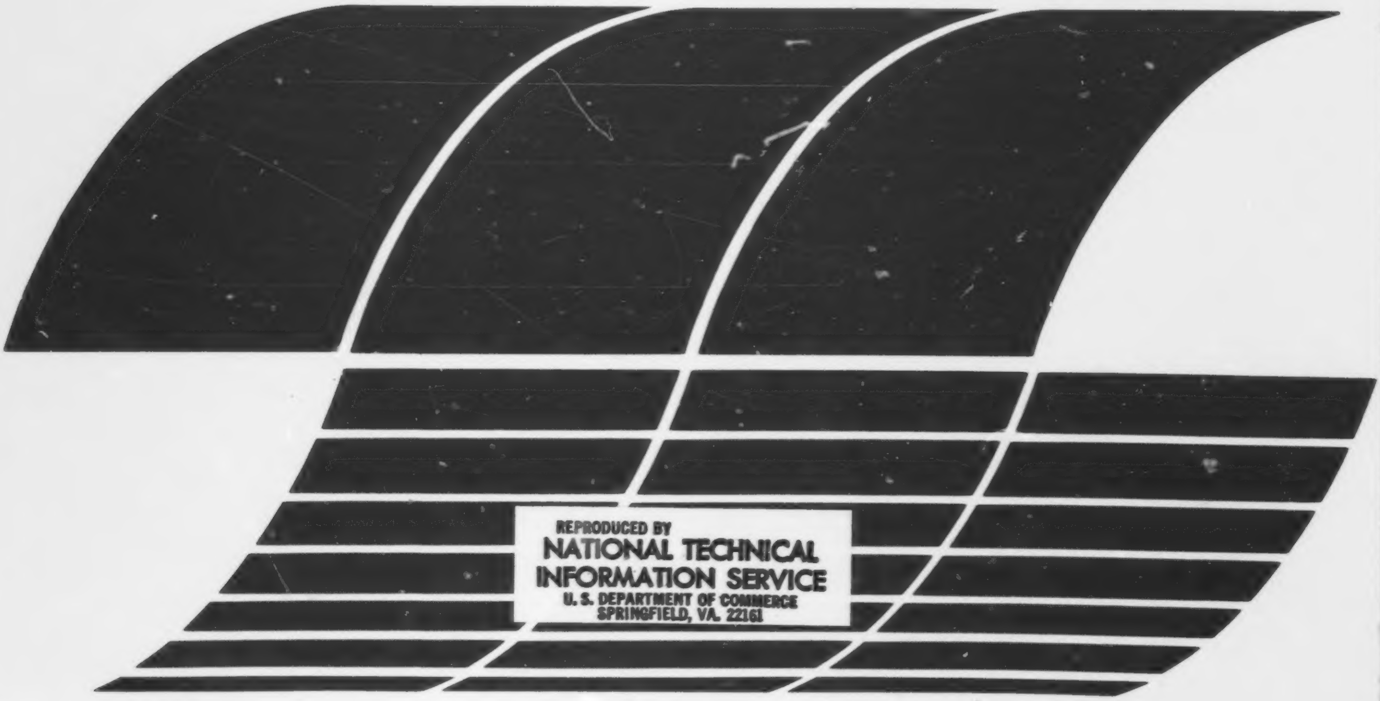
PB 300536

EPA

Groundwater Quality Monitoring of Western Oil Oil Shale Development:

Identification and Priority Ranking of Potential Pollution Sources

Interagency Energy-Environment Research and Development Program Report



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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-023	2.	3. RECIPIENT'S ACCESSION NO. PB300536
4. TITLE AND SUBTITLE GROUNDWATER QUALITY MONITORING OF WESTERN OIL SHALE DEVELOPMENT: Identification and Priority Ranking of Potential Pollution Sources		5. REPORT DATE January 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Guenton C. Slawson, Jr. (Editor)		8. PERFORMING ORGANIZATION REPORT NO. GE77TMP-51
9. PERFORMING ORGANIZATION NAME AND ADDRESS General Electric Company—TEMPO Center for Advanced Studies Santa Barbara, California 93102		10. PROGRAM ELEMENT NO. 1NE625
		11. CONTRACT/GRANT NO. 68-03-2449
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency—Las Vegas, NV Office of Research and Development Environmental Monitoring and Support Laboratory Las Vegas, NV 89114		13. TYPE OF REPORT AND PERIOD COVERED Project Report
		14. SPONSORING AGENCY CODE EPA/600/07

15. SUPPLEMENTARY NOTES
EMSL-LV Project Officer for this report is Leslie G. McMillion. Commercial telephone (702)736-2969, x241 or FTS 595-2969, x241.

16. ABSTRACT

This report presents the development of a preliminary priority ranking of potential pollution sources with respect to groundwater quality and the associated pollutants for oil shale operations such as proposed for Federal Prototype Leases U-a and U-b in Eastern Utah. The methodology used includes description of background information and the proposed oil shale operations as potential pollution sources, characteristics of potential pollutants, area water use, the hydrogeologic framework of the project area, and existing water quality. This information base is then used to evaluate the potential mobility of pollutants in the subsurface through consideration of infiltration, and mobility and attenuation processes in unsaturated and saturated zones. These facts lead to the preliminary priority ranking based on the magnitude of the sources; the toxicity, persistence, etc., of the potential pollutants; the mobility of pollutants in the subsurface; and the potential for harm to water users.

These preliminary results rank the processed shale disposal area, plant process area, and the retention dam area as the general order of priority for monitoring. Within each of these sources areas, individual pollution sources are also ranked with regard to monitoring priority and individual pollutant constituents are also ranked.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Groundwater Movement Groundwater Oil Shale Mine Wastes Waste Disposal Mining Pollution Ranking	Groundwater Quality Water Pollution Sources Monitoring Methodology Pollutant Identification Pollutant Source Oil Shale Mining Eastern Utah	08D 08H 08I 13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 241
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE A11-A01

EPA-600/7-79-023
January 1979

GROUNDWATER QUALITY MONITORING OF WESTERN OIL SHALE DEVELOPMENT:

Identification and Priority Ranking of Potential Pollution Sources

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory—Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- Develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- Demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs.

This report presents the initial phases of a study to design and implement groundwater quality monitoring programs for Western United States oil shale operations. The development of a preliminary priority ranking of potential pollution sources and the pollutants associated with these sources is presented.

The results of this report are the initial segment of the design and field implementation effort. The priority ranking will be combined in subsequent study phases with evaluations of deficiencies in existing or proposed monitoring efforts and alternative monitoring technologies to design a cost-effective groundwater quality monitoring program. This study considered the type of oil shale operation proposed for Federal Prototype Oil Shale Leases U-a and U-b in Eastern Utah. Proposed development plans for these tracts, which include room-and-pillar mining and surface retorting and waste disposal, form the case study evaluations included in this report.

The research program, of which this report is part, is intended to provide technical information and a planning format for the design of groundwater quality monitoring programs for this type of oil shale development. The study results may be used by industrial developers and their consultants as well as by the various local, State, and Federal agencies with responsibilities in environmental monitoring and planning.

Further information on this study and the subject of groundwater quality monitoring in general can be obtained by contacting the Monitoring Systems Design and Analysis Staff, Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Las Vegas, Nevada.

George B. Morgan

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Director
Environmental Monitoring and Support Laboratory
Las Vegas

PREFACE

General Electric—TEMPO, Center for Advanced Studies, is conducting a 5-year program dealing with the design and implementation of groundwater quality monitoring programs for Western oil shale development. The type of oil shale project being evaluated in this study is that presently proposed for Federal prototype oil shale leases U-a and U-b in Eastern Utah. This type of operation includes room-and-pillar mining, surface retorting (utilizing Paraho and TOSCO II processes), and surface disposal of processed (or spent) oil shale. This study is using a stepwise monitoring methodology developed by TEMPO.

This report represents the initial phase of this research program. Described herein is the development of a preliminary priority ranking of potential pollution sources and their associated pollutants. This priority ranking will be utilized in subsequent phases of the research as the basis for defining monitoring needs and for ultimately designing the monitoring program.

In the next phases of this research program, a preliminary monitoring design is to be developed and implemented in the field. Initial field study results may result in a reevaluation of the priority ranking presented in this report. The final product of the 5-year program will be a planning document which will provide a technical basis and a methodology for the design of groundwater quality monitoring programs for oil shale industrial developers and the various governmental agencies concerned with environmental planning and protection.

SUMMARY

General Electric—TEMPO has developed a methodology for designing groundwater quality monitoring programs. This was a conceptual design which involved a series of data compilations and evaluation steps leading to a monitoring system in place. General Electric—TEMPO is now applying that methodology to design a system to monitor the impact of western oil shale development on groundwater quality. This document reports the field survey and literature research performed during the first phase of the design process. The goal of this phase is to identify and rank the major sources of groundwater quality degradation. The site for which the monitoring system is being designed is the Federal Prototype Lease Tracts U-a and U-b in eastern Utah. The oil shale operation proposed for this site includes room-and-pillar mining, surface retorting by the Paraho and TOSCO II process, and surface disposal of spent oil shale.

The priority ranking is based on a sequence of data compilation and evaluation steps. These steps include identification of potential pollution sources, methods of waste disposal, and potential pollutants associated with the various waste sources; and an assessment of the potential for infiltration and subsequent mobility of these pollutants in the subsurface. The three basic criteria used to develop the source-pollutant ranking are:

- Mass of waste, persistence, toxicity, and concentration
- Potential mobility
- Known or anticipated harm to water use.

The information base and related assessments utilized to develop rankings based on these three criteria are summarized in the main body of this report. A ranking based on the first criterion was developed after an in-depth review of operations proposed for Tracts U-a and U-b and of literature on oil shale operations, waste characterization, and control technology. Over two dozen potential sources of groundwater quality impact were identified, including elements of extraction, retorting, upgrading, and waste disposal processes.

These potential pollutant sources vary greatly in mass of waste material. At full commercial scale development, 100,000 tons per day of processed shale (of which perhaps 600 to 2,000 tons may be soluble material) will be produced. Other sources are much smaller in mass (e.g., less than 2,000 tons of spent catalysts per year) or highly variable (e.g., storm runoff), but still may have potential for impact on groundwater quality. A broad spectrum of inorganic and organic constituents are associated with these sources. Salinity,

certain trace elements (As, Se, F), and organics present significant potential pollutants, although characterization (including biological activity) of many constituents (particularly organics) is uncertain.

Available background information and field reconnaissance were employed to describe the hydrogeology and water quality of the study area. These data were used in concert with the source-pollutant characterization to assess the potential for pollutant mobility.

The second ranking criterion calls for setting priorities based on the mobility of the potential pollutants which have been identified. Waste disposal plans for Tracts U-a and U-b include concentration of process and related facilities and common disposal of a wide spectrum of liquid and solid wastes in the processed shale disposal pile. Hence for the mobility evaluations, the individual sources were grouped into source areas. Three source areas are evaluated: the spent shale disposal area, the process area, and the Southam Canyon retention dams. Assessments related to characterizing potential pollutant mobility include infiltration mobility in the unsaturated zone and mobility in the saturated zone. The most likely mobile constituents, mobility pathways, and attenuation mechanisms are identified by this analysis. These data provide second-criterion ranking of potential pollutants. Mobilities may also be enhanced by the proposed reservoir behind the White River dam and by formation of fissures associated with subsidence stress.

The third-criterion ranking addresses potential harm to existing or potential water users. Use of groundwater which flows under Tracts U-a and U-b is largely limited to stock watering and possibly agriculture. Potential future changes in availability and allocation of surface waters could appreciably alter the present perspective on depth-quality restrictions on groundwater. In addition, some potential exists for mobility within the Uinta Formation and associated alluvial materials. By these routes, pollutants may enter the White River alluvium and eventually be discharged into the White River. The consequences of these releases (e.g., high TDS wastes, organics, etc.) on downstream agricultural and municipal users are difficult to quantify because of the uncertainties associated with estimating release rates. For this preliminary assessment, the concentration-toxicity ranking developed for the first criterion expresses the possible hazards to potential water users.

From consideration of the rankings developed for each of these three criteria, a preliminary priority ranking of potential pollution sources and causes and potential pollutants was developed. The highest priority potential pollutant sources were associated with the spent shale disposal area: spent shale; high TDS wastewater, sour water, and retort water used to moisten the spent shale; and spent catalysts deposited in the disposal area. As the retention dams are located below the spent shale piles, these are also the highest ranked sources for the retention dams. Associated with these sources are numerous chemical constituents of which total dissolved salts, selected macroinorganics (sodium, sulfate, and chloride), selected trace elements (arsenic, fluoride, selenium, and molybdenum), and organics (polycyclic aromatic hydrocarbons and carboxylic acids) are considered the most significant potential pollutants. In the process area, the proposed effluent holding pond which drains the process area watershed, raw shale storage, and the tankage area was ranked with highest priority. Dissolved salts, organics, selenium, arsenic, and tankage contents (fuels, oil additives, and ammonia) were considered of highest priority.

The complete priority ranking is shown in the following table. A great deal of effort has been expended on the study of the hydrogeology of the study area and a large amount of research has been conducted on oil shale development and environmental effects. However, significant information voids exist with regard to potential pollutant characterization and the mobility of these materials in the hydrosphere. Hence, professional judgment plays a large role in proposing this preliminary source-pollutant ranking.

This ranking will serve as the basis for the design of a monitoring plan of the Tracts U-a and U-b oil shale development. The next phase of the design program includes evaluation of existing monitoring programs, identification of alternative monitoring approaches to address the source-pollutant ranking, and selection of a monitoring program for field implementation. This implementation will be used to verify (and quite probably revise) the preliminary ranking provided here.

PRELIMINARY RANKING OF POLLUTANT SOURCES AND POLLUTANTS FOR OIL SHALE TRACTS U-a AND U-b

Source Area	Source priority ranking	Potential pollution source	Potential pollutant ranking		
			Highest	Intermediate	Lowest
Spent shale disposal area	Highest	Spent shale	TDS, Na, SO_4, As, Se, F, organics (PAH, carcinogens)	Ca, Mg, Zn, Cd, Hg, B, organics (phenols, etc.)	Pb, Cu, Fe
		High TDS waste water	TDS	---	---
		Sour water	Ammonia, phenols	Organics	---
		Retort water	As, Cl, S, organics (POM, carboxylic acids, phenols)	TDS, organics (amines, etc.)	Carbonates, PO_4, NO_3
		Spent catalysts	As, Mo	Zn, Ni	Fe, Cu, Co
	Intermediate	Stormwater runoff	TDS, organics, As, Se	Na, Ca, SO_4, HCO_3, organics	Zn, Cd, Hg
		Water treatment plant sludges	TDS	Major macroinorganics	Trace metals
		Miscellaneous landfill materials	Sulfides, organics	Sulfides	---
		Sulfur byproducts	Sulfides, sulfates	---	---
		Oily waste waters	Organics	Trace metals	---
		Spent filters	Organics, As	Trace metals	---
	Lowest	Sewage Sludge	Organics	Nutrients	---
		Mine water	TDS, oil and grease	Trace metals, organics	Macroinorganics
		Sanitary waste water	Organics	Nutrients	Macroinorganics
		Surface disturbance	Calcium salts, TDS	Macroinorganics	---
Process area	Highest	Effluent holding pond	TDS, organics	Trace metals, nutrients	---
		Raw shale	TDS, As, Se, organics	Macroinorganics	Trace metals
		Tankage area	Miscellaneous fuels, oil additives, ammonia, TDS	---	---
	Intermediate	Storm water runoff	TDS, organics	Macroinorganics	---
		Miscellaneous process waste streams	TDS, organics, ammonia	Macroinorganics, trace metals	Nutrients
	Lowest	Surface disturbance	Calcium salts, TDS	Macroinorganics	---
Retention dams	(Sources same as spent shale disposal area.)		TDS, organics (PAH, carcinogens, phenols, etc., As, Se, Mo, ammonia, Na, SO_4	Ca, Mg, Zn, Ni, Cd, Hg, other organics	Pb, Cu, Fe, nutrients

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LIST OF ABBREVIATIONS

AA	aza-azarines
ANFO	ammonium nitrate-fuel oil
ASTM	American Society of Testing and Materials
BaP	benzo(a)pyrene
BOD	biochemical oxygen demand
BSF	benzene-soluble fraction
BTU	British thermal unit
CEC	cation exchange capacity
COD	chemical oxygen demand
DMA	designated monitoring agency
Eh	oxidation reduction potential
ESP	exchangeable sodium percentage
ft^3/s	cubic feet per second
ft^3/min	cubic feet per minute
g	grams
HDN	hydrogenation-denitrogenation
HPLC	high-pressure liquid chromatograph
l/min	liters per minute
m^3/s	cubic meters per second
meq/l	milliequivalents per liter
mg/l	milligrams per liter
ml	milliliters
P	precipitation and applied water
PAH	polycyclic aromatic hydrocarbons
PCA	polycondensed aromatics
PCB	polychlorinated biphenols
PET	potential evapotranspiration
PNA	polynuclear aromatics
POM	polycyclic organic materials
ppm	parts per million
SAR	sodium adsorption ratio
ST	storage
TDS	total dissolved solids
TLC	thin-layer chromatography
TOC	total organic carbon
UOC	Union Oil Company
USBM	U.S. Bureau of Mines
WRSP	White River Shale Project

LIST OF MATHEMATICAL FORMULAE ABBREVIATIONS

Q = discharge
T = transmissivity
n = number of flow tubes
Δh = head drop across each square
V = total volume of water
A = area
m = saturated thickness
p = porosity
v = groundwater velocity
L = length of area along which discharge is occurring
S = moisture surplus
P = precipitation
PET = potential evapotranspiration
R/o = runoff
ΔST = change in storage
AET = actual evapotranspiration
K = crop-use coefficient
F = consumptive use factor
t = mean monthly temperature
d = percentage of annual daytime hours during each month
SMR = soil moisture retention

ENGLISH/METRIC SYSTEM

1 cubic meter (m^3) = 1.308 cubic yards
1 cubic meter (m^3) = 6.25 barrels
1 tonne (1 metric ton) = 2,204.6 lbs
1 hectare (10,000 square meters) = 2.471 acres
1 square kilometer (km^2) = 0.3861 square miles
1 liter (1) = 1.0567 liquid quarts

ACKNOWLEDGMENTS

Dr. Guenton C. Slawson, Jr. and Dr. Lorne G. Everett of General Electric—TEMPO were responsible for management and technical guidance of the project under which this report was prepared. Mr. Fred M. Phillips, Department of Hydrology and Water Resources, University of Arizona, Tucson, and Dr. L. Graham Wilson, Water Resources Research Center, University of Arizona, Tucson, were the principal authors of the report. Supporting TEMPO authors were:

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Technical consultation and review for this study were provided by Mr. Glen A. Miller, U.S. Geological Survey, Conservation Division, Area Oil Shale Supervisor's Office.

SECTION 1

SELECTION OF AREA FOR MONITORING

INTRODUCTION

Groundwater presently plays a key role in satisfying United States water needs for municipal, agricultural, and industrial uses. In addition, groundwater discharges to streams and rivers make up a significant percentage of surface water supplies. During low flow periods, almost all surface flow results from groundwater discharges. This interaction between surface water and groundwater is an important consideration in the evaluation of groundwater pollution; subsurface contamination may ultimately affect both surface water and groundwater users.

The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) and the Safe Drinking Water Act of 1974 (P.L. 93-523) provide for protection of groundwater quality. These mandates call for programs to prevent, reduce, and eliminate pollution of both navigable waters and groundwater and for particular protection of drinking water resources. The national responsibility for these activities is given to the U.S. Environmental Protection Agency (EPA). Various State agencies also have similar responsibilities via State enabling legislation.

Synthetic petroleum products recovered from western oil shales are expected to play an important part in supplying future energy needs of the United States. Various estimates of the magnitude of western oil shale reserves have been made. The U.S. Geological Survey estimates that an equivalent of about 640 billion m^3 (4,000 billion bbl) of oil are contained in the oil shales of the Green River Formation of Utah, Colorado, and Wyoming (Table 1-1). These oil shale resources account for 80 percent of the known world resources, but of course are not completely recoverable. Recoverable resources are a function of mining and retorting technology and economics, but may amount to about 290 billion m^3 (1,800 billion bbl) of oil (Hendricks and Ward, 1976). As the estimated remaining world ultimate oil resources are about 320 billion m^3 (2,000 billion bbl) (Tiratsoo, 1976), of which less than 150 billion barrels are in the United States, Western oil shale is clearly a significant energy resource.

The mandates of P.L. 92-500 necessitate implementation of a system for detecting and delineating groundwater pollution before points of use are affected and preferably before pollutants enter the subsurface. Monitoring approaches for these requirements are in marked contrast with more traditional programs aimed at sampling water quality and quantity at the point of

TABLE 1-1. OIL SHALE RESERVES IN THE GREEN RIVER FORMATION[a]

Shale grade liters oil/tonne[b] (gallons oil/ton)[c]	Billion cubic meters (barrels) of oil equivalent			
	Uinta Basin, Utah	Piceance Creek Basin, Colorado	Green River Basin, Wyoming	Total
104-270 (25-65)	14.4 (90)	80.0 (500)	4.8 (30)	99.2 (620)
41.7-104 (10-25)	36.8 (230)	128.0 (800)	64.0 (400)	228.8 (1,430)
20.9-41.7 (5-10)	240.0 (1,500)	32.0 (200)	48.0 (300)	320.0 (2,000)
	291.2 (1,820)	240.0 (1,500)	116.8 (730)	648.0 (4,050)

[a] From Hendrickson, 1975
[b] Tonne = 1 metric ton
[c] Ton = assay ton

supply for a specific use. The design problem described in this report has been addressed using a systematic approach for predictive groundwater quality monitoring developed by General Electric—TEMPO of Santa Barbara, California (Table 1-2). This stepwise methodology includes identification of pollution sources, their associated pollutants, and the potential for mobility of these pollutants in the specific hydrogeologic framework of the study area.

TABLE 1-2. STEPWISE PROCESS OF TEMPO GROUNDWATER QUALITY MONITORING METHODOLOGY

STEP	DESCRIPTION
1	SELECT AREA FOR MONITORING
2	IDENTIFY POLLUTION SOURCES, CAUSES, AND METHODS OF DISPOSAL
3	IDENTIFY POTENTIAL POLLUTANTS
4	DEFINE GROUNDWATER USAGE
5	DEFINE HYDROGEOLOGIC SITUATION
6	DESCRIBE EXISTING GROUNDWATER QUALITY
7	EVALUATE INFILTRATION POTENTIAL OF WASTES AT THE LAND SURFACE
8	EVALUATE MOBILITY OF POLLUTANTS FROM THE LAND SURFACE TO WATER TABLE
9	EVALUATE ATTENUATION OF POLLUTANTS IN THE SATURATED ZONE
10	PRIORITIZE SOURCES AND CAUSES
11	EVALUATE EXISTING MONITORING PROGRAMS
12	IDENTIFY ALTERNATIVE MONITORING APPROACHES
13	SELECT AND IMPLEMENT THE MONITORING PROGRAM
14	REVIEW AND INTERPRET MONITORING RESULTS
15	SUMMARIZE AND TRANSMIT MONITORING INFORMATION

This report presents the results of implementation of the first 10 steps of the monitoring methodology (Table 1-2). These steps lead to a prioritization, or priority ranking, of the most important sources or causes of groundwater quality degradation. This ranking provides a basis for the rational design and implementation of a cost-effective groundwater quality monitoring program for oil shale development.

CRITERIA FOR SELECTING THE MONITORING AREA

The potential for development of oil shale resources in the Western United States is briefly summarized in the preceding paragraphs. Because of the magnitude of these resources and the likely expansion of this new industry to meet ever-accelerating energy needs of the United States, proposed oil shale developments were reviewed by the EPA to identify candidate study areas.

Originally six Federal oil shale leases were proposed. Of these, two each were located in Wyoming (Tracts W-a and W-b), Colorado (Tracts C-a and C-b), and Utah (Tracts U-a and U-b). No bids were received for leasing Tracts W-a and W-b. Various consortiums of oil companies became lessees of the Utah and Colorado tracts, and exploration, environmental baseline studies, and development plans were initiated and are in progress. The vast oil shale resources of Eastern Utah (Figure 1-1) and favorable attitudes toward development at the time of initiation of this study supported selection of this region for study.

After a review of the proposed developments, the Utah Federal lease tracts were considered generally representative of deep mining-surface retorting oil shale developments. The results of this study should be transferable in many ways to the design of groundwater quality monitoring programs for similar oil shale enterprises both in Utah and in other parts of the Western United States. However, the site-specific features of Tracts U-a and U-b, which were considered in this study, produce results that in detail may not be characteristic of other locations in the Western oil shale region. For the study described in this report, proposed development plans for Tracts U-a and U-b have been considered and evaluated. Changes in the proposed development plans, such as implementation of alternative process or control technologies, may alter these assessments.

The monitoring program developed in this study is intended to eventually become part of a State's environmental monitoring programs—including air, land, and water programs. Thus, selection of monitoring areas should be made by the appropriate State agency responsible for water quality monitoring relative to P.L. 92-500 and P.L. 93-523. The basis for this selection is governed by a combination of administrative, physiographic, and priority considerations. The following paragraphs illustrate this area selection process as it might be carried out by the appropriate State agency.

Administrative Considerations

The initiation of a monitoring program requires that a locally designated monitoring agency (DMA) be specified. In many situations, the requisite agency with the necessary technical staff may be a county, district, State, or regional

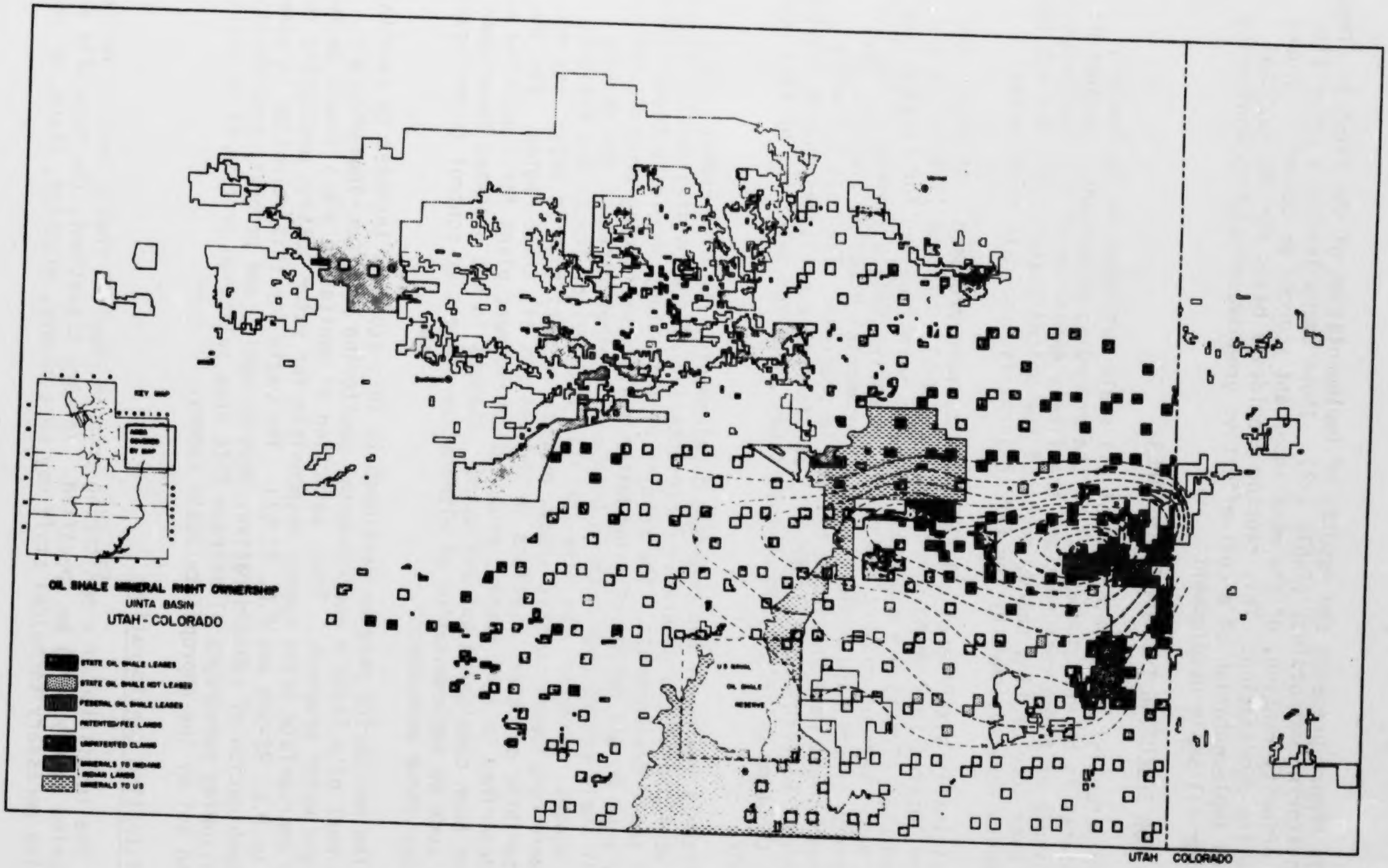

KEY MAP
AREA COVERED BY MAP
OIL SHALE MINERAL RIGHT OWNERSHIP
UINTA BASIN
UTAH - COLORADO
STATE OIL SHALE LEASES
STATE OIL SHALE NOT LEASED
FEDERAL OIL SHALE LEASES
PATENTED/FEE LANDS
UNPATENTED CLAIMS
MINERALS TO INDIANS
INDIAN LANDS
MINERALS TO US
U.S. NAVAL OIL SHALE RESERVE
UTAH
COLORADO

Figure 1-1. Oil shale mineral rights map for Northeastern Utah.

water organization. Thus, the area to be monitored can often be made to correspond to the jurisdictional area of the DMA. The size of a particular area may vary from a few square miles to thousands of square miles. Size alone is less important than the ready accessibility of all portions of the area to the DMA, as well as hydrogeologic knowledge of the area possessed by the DMA.

Selection of the DMA may involve a review of a State's institutional structure. In some instances, it will be readily apparent which agency should be designated as the monitoring agency. In other instances, several agencies may have overlapping responsibility and authority. Situations such as this may require organizational changes to provide for an efficiently operated DMA.

It should be recognized that political boundaries frequently create problems in terms of water management. Such a boundary may cross a major groundwater basin so that, for example, pollutants from an adjoining area may be entering from sources not subject to monitoring by the DMA. Such situations should be minimized as much as possible; alternatively cooperation among DMA's showing common groundwater pollution problems will be essential to the success of their respective monitoring programs.

Physiographic Considerations

The physiographic basis for selecting monitoring areas recognizes that groundwater basins are distinct hydrographic units containing one or more aquifers. Such basins usually, but not always, coincide with major surface water drainage basins. By establishing a monitoring area related to a groundwater basin, total hydrologic inflows to and outflows from the basin are fully encompassed. This permits all pollution sources and their consequent effects on groundwater quality to be monitored by a single DMA. Where basins are extensive, monitoring areas may become too large to be practical. Boundaries should then be drawn parallel to groundwater flows or where cross-flow components are insignificant.

Priority Considerations

Resource administrators at all levels, Federal, State, and local, are faced with a common problem—how to allocate monetary resources equitably to deal with a host of environmental problems. For political reasons, these individuals must be attentive to the needs of all areas under their jurisdiction. Rarely are funds available in a timely manner to deal with more than just a fraction of the problems brought to their attention. A procedure for ranking both existing and potential environmental impacts for monitoring and control would be particularly useful.

The logical starting point, relative to groundwater pollution control, is for the administrator at the highest State level responsible for groundwater quality to issue a request to the various existing local-level agencies, backed by funding, for an inventory of existing and potential sources of groundwater pollution resulting from various activities in each local area. In many instances, e.g., such as in this study, there may be one candidate activity paramount among the rest. Whatever the case, after the initial inventory, preliminary priorities for additional monitoring can be established. Assuming that the State carries out similar inventories of the other environmental impacts it is faced with, the responsible decision-makers will then find it possible to allocate resources for monitoring and control to those areas and problems posing the greatest threat to the State's environmental quality.

The following discussion details the application of the administrative, physiographic, and priority considerations for the selection of the Federal Oil Shale Leases U-a and U-b as the project area, and this will be followed by a description of how the ranking scheme works, before presenting the results of the ranking scheme.

SELECTION OF THE PROJECT AREA

The richest oil shale reserves in the Uinta Basin and the existing oil shale mineral rights ownership are illustrated in Figure 1-1. As indicated, the richest oil shale deposits, and thus the likely locations of the recovery efforts, are located in the White River Basin in Uinta County near the Utah-Colorado boundary. The scope of this study precludes consideration of this entire region of Eastern Utah. In order to select that portion of the Utah oil shale region which is best suited for the goals of this research effort, the administrative, physiographic, and priority considerations outlined above are applied below to the selection of the project area.

Administrative Considerations

The initial administrative consideration is the selection of the DMA. In Utah, there are several organizations which are in some manner involved with water resources. However, environmental areas of all types (water quality, air quality, public health, etc.) are collectively under the Division of Health, a component of the Utah Department of Social Services. The Bureau of Water Quality (part of the Division of Health) appears to be the State agency most suited to become the DMA.

The responsibilities of the Division of Health are presented in the Utah Water Pollution Control Act. These responsibilities include development of programs for the "prevention, control, and abatement of new or existing pollution of the waters of the State." The definition of "waters of the State" includes both surface water and groundwater. Other State agencies, such as the Utah National Resources Department, have responsibilities related to water supply (quantity) and water rights. Operation of a groundwater quality monitoring program should include interaction with these agencies because of the close interrelationship between water quantity and quality. In addition, administrative coordination between the State of Utah and the U.S. Geological Survey, the United States agency for administration of Federal oil shale leases, is indicated at least with regard to operations on these Federal leases.

Other administrative considerations include interaction with local governmental agencies. Limiting the study area to a single county aids in simplifying relations between the monitoring agency and local governments. Coordination of monitoring efforts and access are also enhanced by locating the study area reasonably close to an urban center, in this case, probably Vernal, Utah.

The Federal oil shale leases U-a and U-b provide a development of significant magnitude (i.e., a commercial operation) to obtain results that are generally representative of deep mining—surface retorting oil shale developments. This study area is wholly located within one of the regions of an appropriate DMA, the Utah Bureau of Water Quality.

Physiographic Considerations

The boundaries of the oil shale lease tracts served as a preliminary definition of the monitoring project area (Figure 1-2). These legal boundaries were later superseded by physiographic boundaries delineated by the watersheds encompassing Tracts U-a and U-b (Figure 1-2). This includes the Southam Canyon, Evacuation Creek, and small unnamed watersheds draining into the White River from the lease areas.

As the details of mine and refinery development are better defined and the potential spatial extent for environmental effects becomes more evident, it may be necessary to expand this physiographic region. This eventuality exists with particular reference to potential effects on bedrock aquifers which bound the mining zone.

Priority Considerations

The emphasis of the monitoring program will be to address water quality effects associated with oil shale extraction and processing. Perhaps the primary consideration for selection of the White River Shale Project area as the monitoring area is the significant potential for pollution from the proposed activities. This oil shale region is expected to be among the first developed. Due to the estimated size of the energy reserves in this region, future expanded development is highly likely.

Commercial-scale oil shale mining and processing is in the developmental stages. The quantity and quality characteristics of the wastes to be produced remain speculative. Such uncertainties, in concert with the projected expansion of the oil shale industry, result in a high priority for monitoring. The results of monitoring these initial activities will serve not only to measure the effects of this particular project, but will also serve as input to design planning for subsequent oil shale development.

DEVELOPMENT OF POLLUTION-SOURCE PRIORITY RANKING

The implementation of the ranking scheme calls for three iterations through the steps of the monitoring methodology. Each consideration of the methodology sequence is at a different level of detail and is intended to accomplish different goals. With each iteration, the overall monitoring design program progresses further toward attaining the ultimate monitoring goals embodied in P.L. 92-400 and P.L. 93-523.

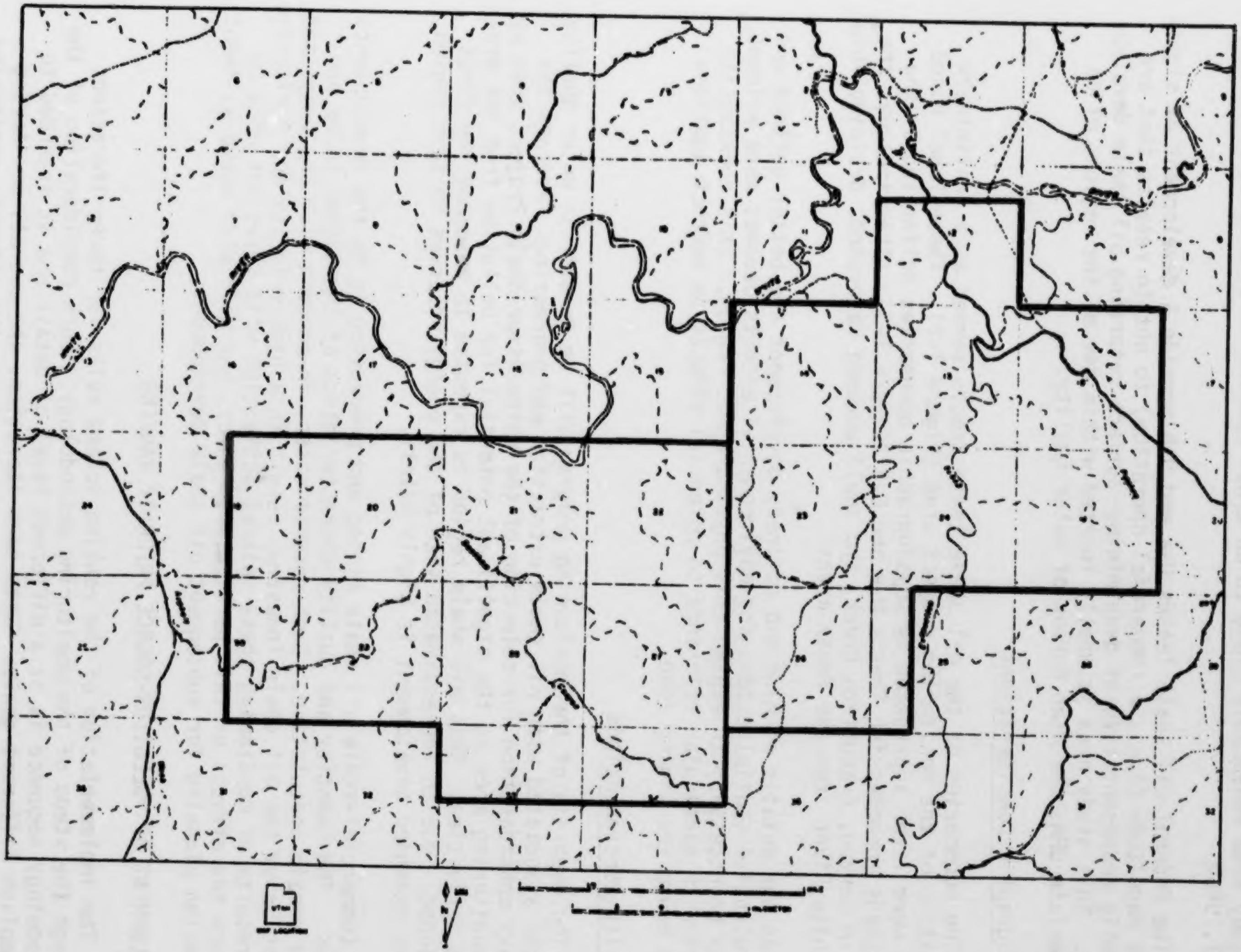


Figure 1-2. Map showing boundaries of Federal Oil Shale Leases U-a and U-b.

Level-One Ranking

The first time through the ranking scheme, several objectives are met:

- Review of the existing data and information on known sources and causes of groundwater pollution
- Identification of potential sources and causes of groundwater pollution
- Identification of potential pollutants associated with the pollution-source groupings
- Evaluation of the hydrogeologic framework in the project insofar as it relates to the known and potential sources and causes of pollution
- Superimposition of the sources and causes of pollution on the hydrogeologic framework to determine their mobilities.

The final goal in this first pass through the ranking scheme will be establishment of priorities for monitoring those sources which appear to present the greatest threat to the area's groundwater quality. Unless a great deal of study has previously taken place in an area, considerable hydrologic judgment and, more importantly, a sound appreciation for the mechanisms of transport of the various pollutants through the soil and vadose zone will be required to make the ranking.

When the preliminary ranking is completed (Step 10), the DMA will then be in a stronger position to approach the appropriate funding agency for support to deal with the problem of groundwater quality degradation. It will be particularly important to try to present some estimate of damages which may result if monitoring, and eventually control, are not undertaken.

Economics

Acceptance by the funding agency that a potential problem exists should result in funding to design a monitoring program, complete with data storage and dissemination provisions. Design of the monitoring program will involve a review of all existing monitoring activities in the project area, the selection of cost-effective monitoring alternatives, and the implementation of those alternatives which constitute the preferred monitoring program. Before the preferred monitoring program can be implemented, the funding agency must again be consulted to gain funding for implementation. More often than not, tradeoffs will be required when funding is not completely available.

Level-Two Ranking

Implementation of the monitoring program will require a return to the beginning of the methodology steps (Table 1-2). This time the objective will be to verify the preliminary ranking sources with hard data. Considerable time may be involved in this exercise, depending on the number of sources involved and the size of the area—several years to a decade or more to reach a mature stage. Undoubtedly the intensive monitoring will result in a revision of the original priorities. Some monitoring activities will have to be decreased or eliminated, while others will need to be intensified.

Utilizing the results of the second pass through the ranking scheme, a much more accurate estimate of the threat to the area's groundwater quality will be available, and controls or mitigating measures can be devised to deal with the threat. If the need for instituting controls is obvious after the first preliminary ranking, they should be implemented at that time. The monitoring design process aids in setting priorities for implementing migration or control procedures. The implementation of controls will again require funding by the appropriate State agency.

Level-Three Ranking

The final iteration of the ranking steps will involve monitoring to check on the effectiveness of the controls that are implemented. If these controls prove effective, then the intensity of monitoring can be reduced and eventually dropped if the threat can be shown to no longer exist.

New sources of potential pollution will continually appear. The monitoring program should plan to include these sources. They should be brought into the program through the orderly process of Environmental Impact Reviews by State and Federal agencies.

SECTION 2

POLLUTION SOURCES, CAUSES, AND METHODS OF DISPOSAL

OVERVIEW OF UTAH OIL SHALE REGION

The White River Shale Project (WRSP) is located in Northeastern Utah and encompasses the two Federal Oil Shale Leases U-a and U-b (Figure 1-2). These lease tracts are 2,068 hectares (5,110 acres) each in size.

Tract U-a is located immediately south of the White River in the eastern part of the Uinta Basin. The valley of the White River occupies a narrow strip about 240 meters (800 feet) wide in the northcentral part of the tract. Southam Canyon, a slightly meandering drainage, extends northwestward across the tract and joins the White River just outside the tract. Numerous minor drainages in the tract are tributary to Southam Canyon and to White River, the only perennial stream. The topography is characterized by high, sinuous ridges bounded by cliffs and separated by lower areas of narrow branching ridges and stream valleys. Altitudes within the tract range from about 1,494 meters (4,900 feet) on the White River to about 1,817 meters (5,960 feet) in the southcentral part. Greatest altitude difference in a short distance is about 137 meters (450 feet) in eight-tenths of a kilometer (one-half mile) in the northwestern corner of the tract.

Tract U-b, which abuts Tract U-a, is located immediately south of the White River in the eastern part of the Uinta Basin. The White River is a perennial stream and flows near the northern boundary of the tract. The canyon of Evacuation Creek trends northward across the central part of the tract. East of Evacuation Creek the topography is characterized by rounded, forked ridges with scattered ledges and cliffs. West of Evacuation Creek the terrain is more rugged and is characterized by ledges and cliffs along the canyon walls and numerous buttes along the drainage divides. Altitudes range from 1,512 meters (4,960 feet) along the White River to about 1,783 meters (5,850 feet) near the southwest corner. Greatest altitude difference in a short distance is about 91 meters (300 feet) in eight-tenths of a kilometer (one-half mile) in the southwestern part of the tract.

The estimated average thickness of the Tract U-a oil shale sequence, that averages 125 liters of shale oil per tonne (30 gallons per ton), is about 13.5 meters (45 feet). This is based on data from core holes outside the tract and from exploratory wells within the tract. Overburden above the Mahogany Zone (the major oil shale-bearing zone) ranges from 167 to 372 meters (550 to 1,225 feet) and the average is approximately 258 meters (850 feet). The shale oil resource recoverable from the tract by underground mining methods is estimated to be 39.1 million m^3 (244.4 million bbl). Nahcolite is probably present in the tract as very thin lenses or beds and small pods. There are no reports of significant amounts of surface or subsurface bituminous sandstone in the tract, and no obvious gilsonite (uintaite) veins. The Southam Canyon field has produced gas from the Wasatch Formation in Tract U-a. Although the Uinta Formation produces gas in some parts of the Uinta Basin, it is very unlikely that commercial amounts of gas in this formation underlie Tract U-a.

Assayed samples from core holes in Tract U-b show the average thickness of oil shale yielding an average of 125 liters of oil per tonne (30 gallons per ton) to be approximately 15 meters (50 feet). Overburden above the principal oil shale beds ranges from 91 to 380 meters (300 to 1,150 feet) and the average is about 213 meters (700 feet). The shale oil resource recoverable from the tract by underground mining methods is estimated to be 42.6 million m^3 (265.8 million bbl). Nahcolite occurs as very thin lenses or beds and small pods in the upper part of the Green River Formation. No oil or gas has been discovered in the tract nor is there any known occurrence of significant amounts of bitumen in sandstone. One narrow gilsonite vein, less than two inches wide, outcrops in the westcentral part of the tract.

The White River Shale Project is a venture formed by Phillips Petroleum Company and Sunoco Energy Development Company, owners of lease U-a, and Sohio Petroleum Company, owner of lease U-b. The shale sequence to be mined is about 17 meters (55 feet) thick. Present plans call for raw shale extraction to be by room-and-pillar methods. The shale is planned to be processed on the surface, at a common facility for both tracts, using three retort types:

- Paraho direct heat mode
- Paraho indirect heat mode
- TOSCO II.

The Paraho retort uses hot gases to pyrolize the kerogen in the oil shale. In the directly heated mode, the gases are provided by combustion of carbonaceous residue in the pyrolized shale, and in the indirectly heated mode they are provided by indirect heating of recycled gases from the retort. The indirectly heated mode produces higher BTU gases.

Finely ground raw oil shale produced by crushers will be processed by the TOSCO II retorting method which utilizes heated alumina balls to volatilize the kerogen. The solid oil shale residue (processed or spent shale) from the various retorts will be disposed of in surface dump sites. The crude shale oil will be upgraded onsite by severe hydrotreating to render it amenable to pipeline transport.

Mining and refining development is scheduled in four phases:

- Phase I – Settlement of lease agreement; mineral exploration; formulation and approval of the Detailed Development Plan (DDP); environmental baseline studies

- Phase II — Sink mine access to Mahogany Zone; mine maximum of 9,100 tonnes (10,000 tons) per day; operate single Paraho retort; decide feasibility of commercial operation (Figures 2-2 and 2-3)
- Phase III — Develop commercial operation of 73,200 tonnes (84,000 tons) per day mining from U-b and refinery capacity of 8,000 m^3 (50,000 bbl) per day (first train operation) (Figures 2-2 and 2-4)
- Phase IV -- Develop additional operation of 73,200 tonnes (84,000 tons) per day mining from U-a and increase refinery capacity to 16,000 m^3 (100,000 bbl) per day (second train operation) (Figures 2-2 and 2-4).

These phases are projected to cover some 10 years before initial commercial mine operation commences and approximately 20 years total (Figure 2-1).

The waste disposal plans described in this report and evaluated in this study are as presently proposed by the White River Shale Project (WRSP, 1976a). Provisions of the U.S. Resource Conservation and Recovery Act of 1976, referring to the handling and disposal of hazardous wastes, may result in alteration of these disposal plans and hence the final design of the monitoring program.

SOLID WASTE SOURCES AND DISPOSAL METHODS

Solid waste generation and disposal methods are summarized in Figure 2-5. Figures 2-6 and 2-7 are flow diagrams for Phases II through IV. A detailed discussion of construction- and operation-generated solid wastes is presented in the following paragraphs.

Construction and Mine Development

During construction of the mine adits and processing plant, about 161 hectares (400 acres) of land will be denuded, excavated, or disturbed (Table 2-1). This altered land surface presents a potential groundwater pollution threat due to leaching through the disturbed soil.

In the course of Phase II, about 48 hectares (120 acres) will be affected. During Phases III and IV, an additional 113 hectares (280 acres) will be disturbed. Most of the debris from the mine shafts will go onto the spent shale pile, but about 76,000 m^3 (100,000 yd^3) from ventilation shafts on Tract U-b will be placed in a landfill of 1 hectare (2.4 acres) (WRSP, 1976a). The location of this landfill has not been specified.

Some of the topsoil which is suitable for aiding revegetation will be removed and stockpiled. This topsoil will later be spread over areas to be revegetated. Revegetated areas where the soil is deficient will be fertilized, giving rise to another possible source of leached pollutants.

Large amounts of debris will be generated during construction of the facilities for various phases of development. This will consist of scrap lumber and metal, excess concrete, packing containers, and similar construction waste, and general trash and garbage from shop, warehouse, and employee facilities. Construction waste is expected to average about 13.7 tonnes (15 tons) per day and general waste about 1.8 tonnes (2 tons) per day. The former will be collected in twenty 34 m^3 (45 yd^3) bins and the latter in one 3.8 m^3 (5 yd^3) bin for truck haulage to a landfill where it will be spread and covered. For the construction period of Phase II, the waste will be disposed of in a side canyon of Southam Canyon. The area method of landfilling will be employed. A catchment will be constructed west of the landfill to catch any leachate. The landfill will be covered with spent shale during the latter part of Phase II. The same procedure will be followed during construction for Phases III and IV.

Mine and Refinery Operation

Raw Shale—

A large amount of raw shale dust and fines will be disposed of as waste. During Phase II processing, no TOSCO retorts will be in operation, and all of the shale fines from the crushers will be dumped on the spent shale pile. About 1,180 tonnes (1,300 tons) per day of this fine shale will be produced. During Phases III and IV, the fine shale will be retorted but significant amounts of shale dust too fine to be retorted will be produced by the crushers. At full-scale operation, the shale dust will total about 519 tonnes (570 tons) per day, of which 491 tonnes (540 tons) will be raw shale dust and the rest spent shale dust. This dust will be trapped by water sprays in the dust control system and pumped to the processed shale moisturizer, and thence to the spent shale pile. About 36 tonnes (40 tons) per day of raw shale dust will be produced by the primary crushers located in the mine during full operation. This dust will be pumped as slurry to mined out areas and will not be disposed of on the surface.

Stockpiles of crushed raw shale will be maintained on the surface during plant operations. Although not actually waste products, these piles do present a groundwater pollution potential. The shale will be stored in unprotected conical piles on the ground surface.

Spent Shale—

By far the largest single possible groundwater pollution source is the processed shale. Under the Unified Soil Classification System, the shale residue has the texture of a silty gravel, and exhibits little resistance to wetting, in contrast to spent TOSCO shale. The shale residues will have a pH of 10.7 to 11.8 and will contain from 6,000 to 20,000 ppm of soluble salts.

During Phase II, 5,270 tonnes (5,900 tons) per day of spent shale will be produced. This shale will be moisturized to about 10 percent by weight and moved by conveyor belt to the disposal site where it will be loaded on trucks for distribution and dumping (Figure 2-8). About 53 hectares (130 acres) on the eastern edge of Southam Canyon will be covered to a maximum depth of 30 meters (100 feet) to accommodate a total volume of 3.4 million m^3

(4.5 million yd^3) of spent shale. This pile will contain no TOSCO processed shale, but will contain a larger amount of raw shale fines than the Phases III and IV shale pile.

The processed shale pile will gradually cover Southam Canyon in a fanlike pattern over the course of Phases III and IV (Figure 2-9). The method of transport will be the same, except that the conveyor belt will be relocated. The total area covered during the life of the project will amount to 930 hectares (2,300 acres) to a maximum depth of about 150 meters (500 feet). The total volume is projected to be 725 million m^3 (950 million yd^3).

At the disposal site, moisturized shale will be dumped on the ground surface and compacted by the trucks driving over it. The upper surface of the pile will be specially compacted to reduce its permeability to 2.5 to 5 cm (1 to 2 inches) per hour.

The DDP states that the spent shale will be moisturized to 10 percent by weight and will have a field capacity of about 20 percent (White River Shale Project, 1976a). Due to the arid nature of the region (potential evapotranspiration is about 48 inches and precipitation is about 10 inches), most precipitation will be absorbed by the spent shale and subsequently discharged to the atmosphere as evapotranspiration draws it to the surface, according to the DDP. However, depending on the exact nature of the Paraho and TOSCO spent shale mixtures, the details of the dumping and compaction, the degree of revegetation, and the climatic conditions under which infiltration might occur, leachate from the shale pile could become a source of groundwater pollution. A particularly critical period is during buildup of the spent shale pile, prior to compaction, grading, covering with topsoil and revegetation. After revegetation, decay of sealants used between revegetation trenches may be followed by formation of a surface layer of concentrated salts and other materials brought to the surface by capillary action in the compacted surface. These materials may subsequently wash into revegetation trenches and infiltrate into the shale pile.

During Phase II, a small retention dam will be constructed to the west of the shale pile to catch any runoff or leachate. Before Phase III, a larger dam will be placed at the mouth of Southam Canyon for the same purpose. Any water which collects in these impoundments will be used for moisturizing the shale.

Revegetation—

The spent shale disposal area will be revegetated. When filling is complete in an area, the surface will be trenched and fertilized soil deposited in the trenches to support revegetation. The surface of the shale pile will be temporarily sealed to direct precipitation into the trenches (Figure 2-10).

The edges of the pile will be formed to a 4:1 slope and contoured to fit the topography. Revegetation trenches will be constructed along the face to intercept runoff. To further reduce erosion, three 6-meter (20-foot) wide benches with a 10 percent reverse slope will be provided. The top of the pile will be diked to prevent runoff from the surface. Figure 2-11 is an artist's conception of the appearance of the side of the shale pile after revegetation.

Oil Upgrading Wastes—

Large quantities of industrial wastes will be generated by the processes of recovering and treating the shale oil. All of these wastes will be hauled to the shale pile, moisturized, spread, and covered with spent shale. Alternatively, some of these materials (e.g., spent catalysts) may be reclaimed.

The most important category of industrial waste from the standpoint of pollution potential is the catalysts and filters used in the hydrotreating process, consisting of activated carbon and diatomaceous earth filters which have become clogged, and spent catalysts. These wastes will total about 1,550 tonnes (1,700 tons) per year. The largest single contribution will be 1,180 tonnes (1,300 tons) per year of spent HDN (proprietary) catalyst. Industrial solid wastes are detailed in Table 2-2. Along with the filters and catalysts, about 637 tonnes (700 tons) per year of more inert wastes will be buried, including attrited alumina heat transfer balls from the TOSCO retorts and burned fire bricks.

Processing Material Stockpiles—

During operation, the catalyst and filter material described above will be stockpiled on site prior to use. Hence, the potential exists for spills and releases of these materials from stockpiles. Releases of these potentially toxic materials from stockpiles are less likely than releases after use.

Miscellaneous Solid Wastes—

At full commercial operation, approximately 4.6 tonnes (5 tons) per day of general employee and facility garbage and other waste will be produced. During Phase III operation, about half this amount will be disposed of, and during Phase II, far less than half. This waste will be disposed of by sanitary landfill in Southam Canyon. At the beginning of Phase II, the landfill will be on the ground surface; after mining commences, it will be interlayered with the spent shale.

A small amount of sludge will be produced by the sanitary sewage secondary treatment plant. This will amount to about 0.46 tonnes (0.5 ton) per day (dry weight) at full production. This organic material will be stored in drying beds for use in conditioning soil for revegetation.

River water used for plant operations will be treated, generating approximately 2.7 tonnes (3 tons) per day (dry weight; 270 tonnes per day wet weight) of sludge material. These wastes will be collected in a settling tank, then pumped to the processed shale moisturizer and conveyed to the processed shale disposal site.

LIQUID WASTE SOURCES AND DISPOSAL METHODS

Construction and Mine Development

During facility construction and mine development, the volume of liquid wastes will be small. Portable chemical toilets will be used during construction, with at present unspecified disposal off-tract, until completion of the sanitary waste water treatment plant. Stockpiles of supplies, such as gasoline and oils, and shop and maintenance areas where these materials are used, are other potential construction-related pollution sources.

Approximately 0.9 tonne (1 ton) of waste oil per week will be generated. This will be collected in drums for salvage or disposal offsite. Plans for disposition of these materials are not complete at this time.

Mine and Refinery Operation

General water use and waste product generation projections for proposed operations are given in Figure 2-12. The various processes involved in mining, processing, and upgrading the shale oil will generate a large volume of waste waters of many types. During Phase II, total waste water, including sanitary waste water, oily waste water, storm runoff, sour water bottoms, high TDS waste water, and sulfur slurry flow will amount to about 230 l/min (liters per minute) (60 gal/min) and, during Phase II about 5,800 l/min (1,530 gal/min). Although a large amount of water will be used for dust control and other uses (680 l/min [180 gal/min]) during Phase II (12,000 l/min [6,065 gal/min] during Phase IV), a high level of reuse is planned so that no surface or below-ground discharge of waste water is planned. The magnitude and mode of collection of various waste water streams are summarized in Table 2-3.

Retorting and Related Facilities—

Waste water from cleaning the facilities and industrial area will contain oil and other organic products, suspended solids, and miscellaneous chemicals. The sewer will be vapor sealed and vented to prevent fires or explosions from spreading through the plant in the sewers. The oily waste water will be treated by gravity separation and the skimmings will be stored and recovered. The remaining water may be treated by flotation, and then will go to the waste water holding pond. Phase II is expected to produce about 68 l/min (18 gal/min) and Phase IV about 1,100 l/min (290 gal/min) of waste water.

The retorting and upgrading processes will also produce waste water. The retort units, hydrotreating facilities, light-ends compression units, flares, and the ammonia wash will all emit sour water containing sulfides, ammonia, phenol, and other organics. The Phase II operations will produce about 95 l/min (25 gal/min) and Phase IV operations about 4,740 l/min (1,250 gal/min) of sour water. This water will be stripped and reused at the rate of 3,030 l/min (800 gal/min), and the other 1,710 l/min (450 gal/min) of stripper bottoms will be released to the oil water sewer and thence to the waste water holding pond.

The water supply treatment sedimentation unit, ion exchange regenerator, cooling tower, tail gas unit, sulfur plant, hydrogen plants, hydrotreating units, and the fines retorts will produce water with a high inorganic dissolved solids level. This water will be collected in a separate sewer and stored in a high-TDS waste water tank. The water in the tank will be used for dust control in the secondary crusher scrubbers and subsequently to wet the processed shale. The total high-TDS waste water in Phase II is estimated to amount to 38 l/min (10 gal/min) and in Phase IV to 1,940 l/min (775 gal/min). Proposed development plans do not call for treatment of this water.

Sulfur byproduct, disposed of as a slurry, is included as a waste water. About 150 tonnes (165 tons) per day of pure sulfur will be available for sale to the fertilizer and chemical industries, but 79 tonnes (87 tons) per day (2.1 tonnes [2.3 tons] per day during Phase II) of low-grade sulfur will be slurried and added to the waste shale before it is transported to the disposal site. This sulfur is produced by the Stretford unit. Sulfur, however, is not in great commercial demand; therefore, the commercial-grade sulfur may also be transported to the shale pile.

All of these waste water streams, whether treated or not, will be used for dust control in the scrubbers. About 95 percent of this water will be recovered, with whatever additional materials it has acquired from the raw shale dust, and used for processed shale wetting. The processed shale will be wetted to about 10 percent by weight.

Mine Water—

Saline waters produced in the mine will be pumped into the high-TDS waste water holding tank. No treatment will be provided. Sources of mine waste include the Bird's Nest Aquifer (downward leakage), and sources of recharge to the Bird's Nest Aquifer. The head in the Douglas Creek is above the mining zone and creates a moderate potential for upward leakage into the mine.

Explosive Residues—

A serious source of water pollution in some mining areas is explosive residues. On the Utah tracts, ammonium nitrate-fuel oil-based explosives will be used in the mine. In the event of water leakage through the mined area, nitrates may contaminate the area groundwaters. Collected mine water will be pumped to the surface to be used for moisturizing the processed shale. Hence these explosive residues may also end up in the shale pile.

Sanitary Wastes—

Employee facilities will produce waste water needing sanitary treatment. The Phase II flow will be about 35 l/min (9 gal/min) and the Phase IV about 170 l/min (45 gal/min). Portable chemical toilets will be used in the mine, and their contents dumped into the sanitary sewers. Sanitary waste water will be treated by sedimentation, biological oxidation, and clarification processes, followed by chlorination. It will then be discharged to the waste water holding pond. All water in the holding pond will be used for dust control in the secondary crushers.

Storm Water Runoff—

The largest single waste water stream on an instantaneous basis (though not on the average) is expected to be storm runoff. The runoff from the plant itself will be carried in storm sewers, and the runoff from the rest of the plant area in open ditches, to a screening, degritting, and oil gravity separation facility. In violent storms, the degritting and oil gravity separation may be bypassed. The water will then be stored in the waste water holding pond. The holding pond and the drainage facilities are planned to handle a 100-year flood runoff of 231,000 l/min (61,000 gal/min) from the plant area.

Waste water will be created by storm runoff from the spent shale pile in Southam Canyon or by leachate from under the pile. This water will very likely have an extremely high inorganic salt level, and possibly dangerous levels of organic compounds. Surface runoff will be trapped by the impoundment on the western side of Southam Canyon (Phase II) or at the mouth of Southam Canyon (Phases III and IV) and pumped back up to the shale pile for dust control and compaction wetting.

Catastrophic Failures—

In addition to pollution potential from normal plant and mine operations, the potential also exists for groundwater quality degradation from accidents or equipment failure. It is evident that a major fire or explosion at the retorting or upgrading facilities could release a great variety of contaminants which could infiltrate to the water table. More likely, and potentially more serious, is tank failure.

The largest tankage volume will contain crude shale oil in a number of containers totaling 240,000 m^3 (1,500,000 bbl). Also stored in large volumes are naphtha, 56,000 m^3 (350,000 bbl); high total dissolved solids (TDS) waste water, 35,200 m^3 (220,000 bbl); fuel oil, 11,200 m^3 (70,000 bbl); ammonia, 8,000 m^3 (50,000 bbl); and diesel fuel, 5,600 m^3 (35,000 bbl). Stored in smaller volumes are butane, liquid nitrogen, and shale oil pour-point depressant.

All tankage will be stored in a dike and holding pond system to minimize the effects of tank failure. According to the lease terms, this dike and holding pond system must be capable of containing 150 percent of the tank capacity it surrounds plus the 100-year flood runoff for the drainage area of the tanks. However, the WRSP considers this stipulation excessive and is petitioning for its mitigation.

Miscellaneous Liquid Wastes—

Approximately one ton per week of waste oil and chemicals will be generated by equipment maintenance and plant laboratories. These wastes will be collected in drums for salvage or disposal. Their transfer and handling create some potential for spillage and subsequent contamination of groundwater.

MISCELLANEOUS SOURCES AND CAUSES

Exploration Drilling and Testing

During initial exploration of the tracts and development of baseline data, numerous holes were drilled to collect geologic, lithologic, resource, and hydrologic data. Such holes may be or become pollution sources by the following mechanisms:

- Flow of groundwater to the surface
- Aquifer interconnections due to improper well completion or plugging
- Pumping of wells during hydrologic surveys (Section 5).

Exploration holes are identified in Figure 5-4.

Oil and Gas Wells

Eight oil and gas wells have been drilled on the tracts. Only one, in the central portion of Tract U-a, has produced significant amounts of gas. The others were dry holes. By the mechanisms identified above, these holes are potential pollution sources.

White River Dam

Oil shale development will require large volumes of industrial quality water. The source of water favored by the White River Shale Project is a dam proposed by the State of Utah, to be built on the White River. The dam site is just below the mouth of Southam Canyon. The dam will be 38 meters (125 feet) high and will impound a lake with a surface elevation of approximately 1,524 meters (5,000 feet). The lake will extend upstream well past Hell's Hole Canyon.

Such a dam and lake could seriously alter the hydrogeologic framework. The hydrology of the White River would obviously be drastically changed. The lake could have several effects on the groundwater. The Bird's Nest zone crops out beneath the projected surface of the lake. The increased hydrostatic head of the lake would reduce discharge of water from the Bird's Nest Aquifer into the White River at the point where the Bird's Nest zone outcrops cross beneath the lake. Water might drain into the mine workings, particularly in the event of mine subsidence and fracturing. The hydrostatic pressure of water penetrating laterally into the Uinta Formation might open bedding plane seams, allowing an increased flux of leachates or pollutants entering from above.

Subsidence

Present plans for room-and-pillar extraction will aid to mitigate subsidence potential. Additional data on oil shale compressibility and overburden rock mechanics are needed to even qualitatively address this problem. Related factors are formation of fissures above the mining zone which could affect pollution potential of mine water, effects of the White River Dam, and disruption of the spent shale pile which will lie above the U-a mine zone.

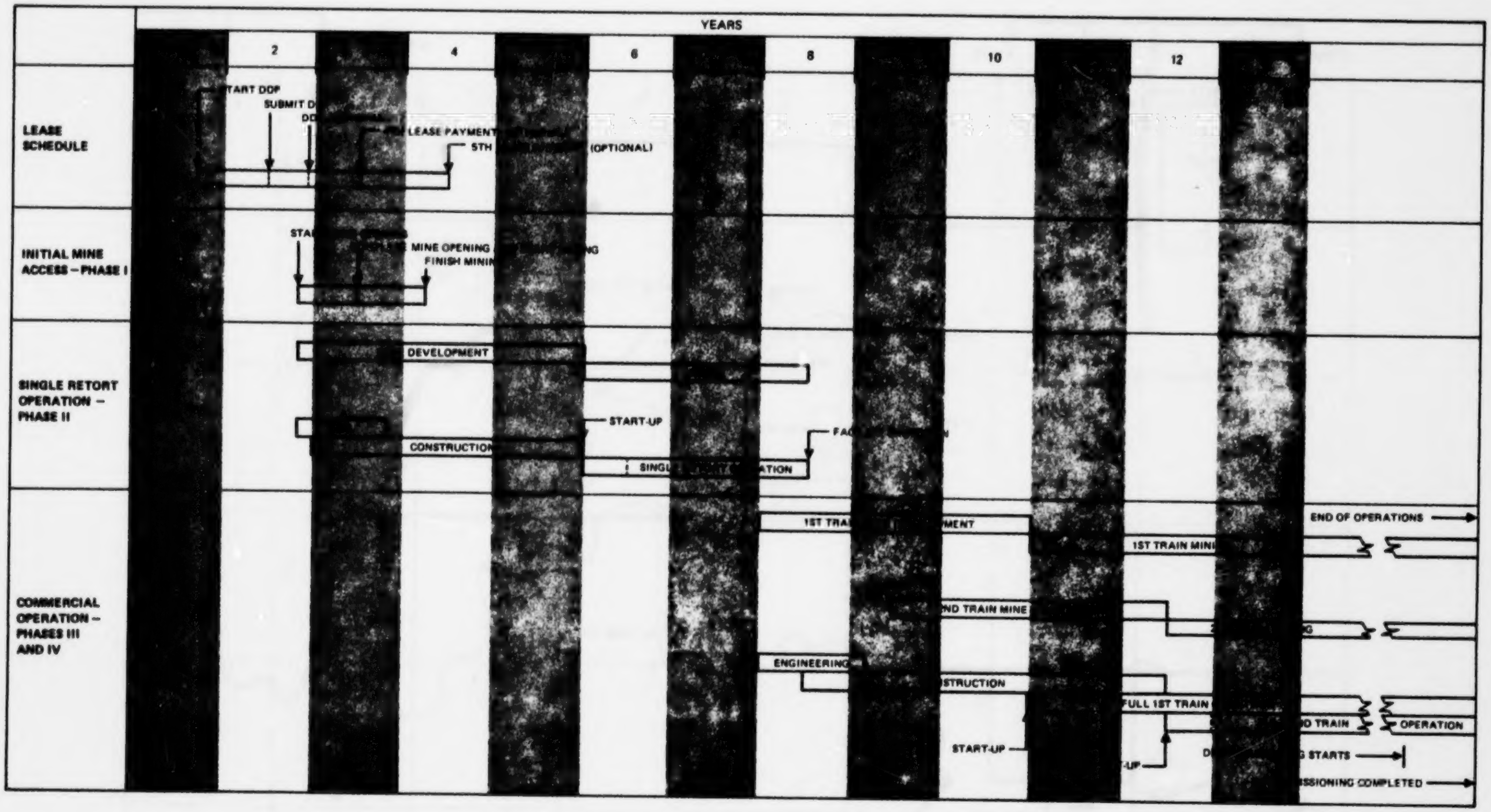
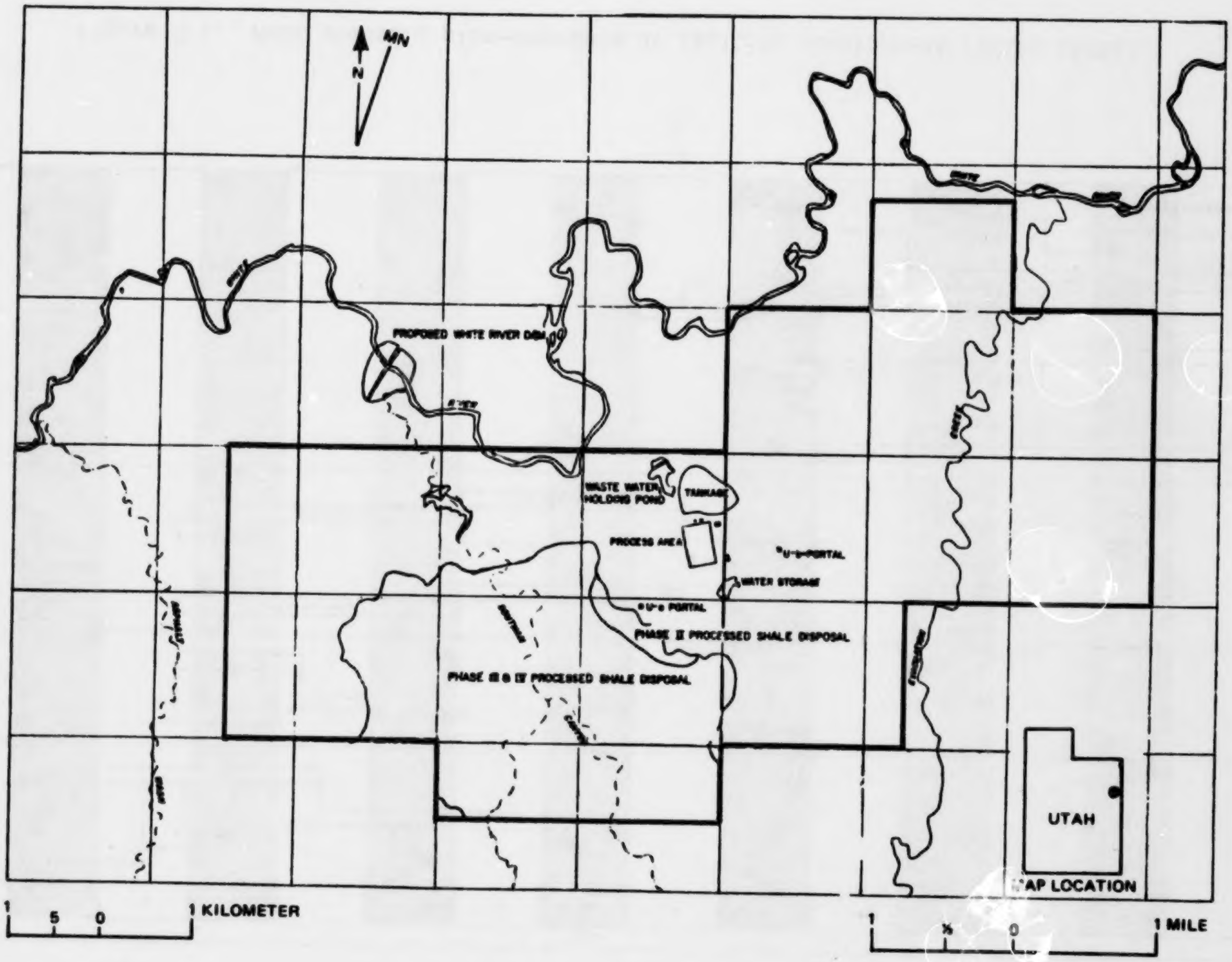
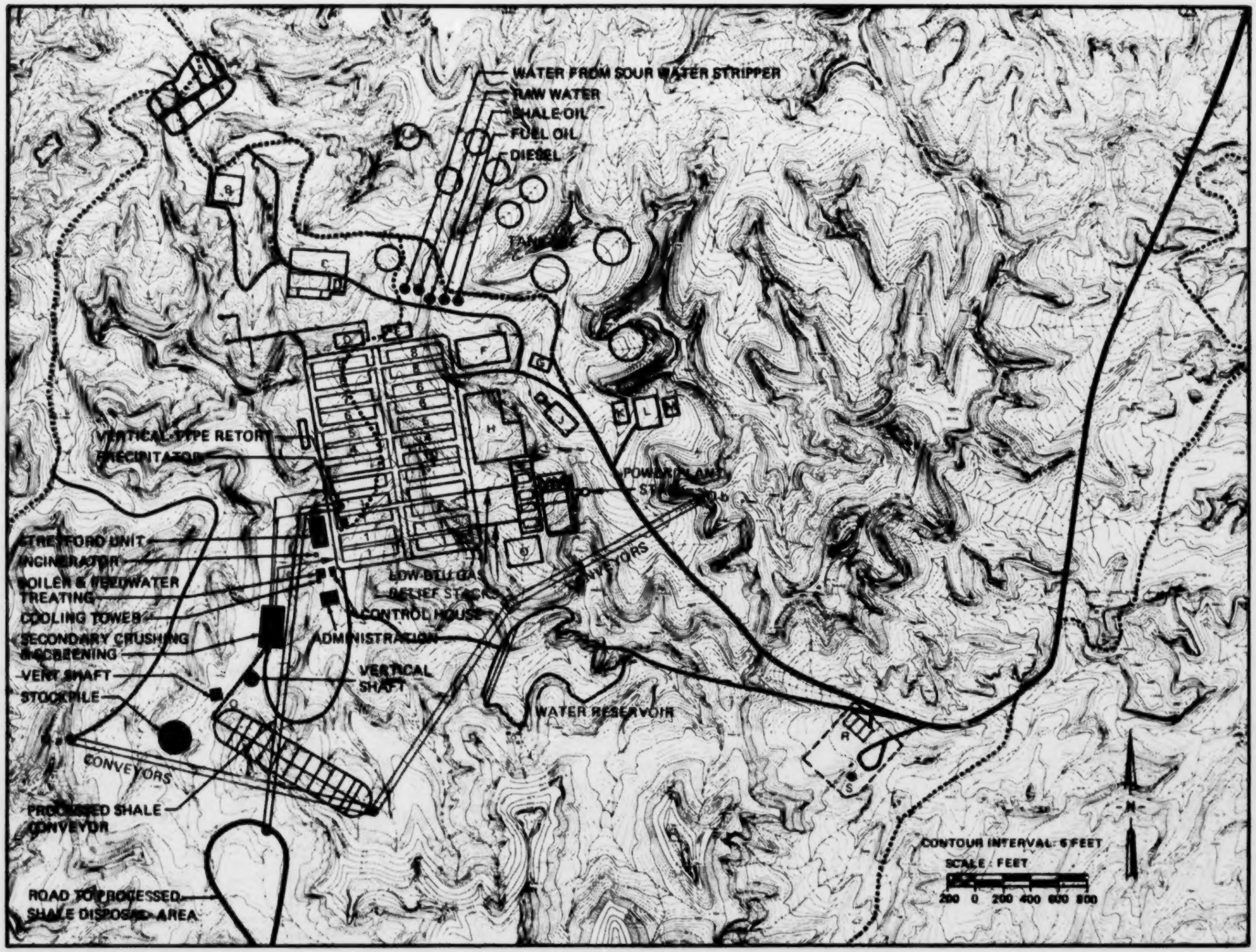


Figure 2-1. Most probable plan–schedule of facility development (WRSP, 1976a).



MN
N
PROPOSED WHITE RIVER DAM
WASTE WATER HOLDING POND
TANKAGE
PROCESS AREA
U-b PORTAL
WATER STORAGE
U-a PORTAL
PHASE II PROCESSED SHALE DISPOSAL
PHASE III & IV PROCESSED SHALE DISPOSAL
UTAH
MAP LOCATION
1 5 0 1 KILOMETER
1 ½ 0 1 MILE

Figure 2-2. General site plan for development of Tracts U-a and U-b.


WATER FROM SOUR WATER STRIPPER
RAW WATER
SHALE OIL
FUEL OIL
DIESEL
TANKS
VERTICAL-TYPE RETORT
PRECIPITATOR
STRETFORD UNIT
INCINERATOR
BOILER & FEEDWATER TREATING
COOLING TOWER
SECONDARY CRUSHING & SCREENING
VENT SHAFT
STOCKPILE
CONVEYORS
PROCESSED SHALE CONVEYOR
ROAD TO PROCESSED SHALE DISPOSAL AREA
LOW-BTU GAS RELIEF STACK
CONTROL HOUSE
ADMINISTRATION
VERTICAL SHAFT
POWER PLANT STACK
CONVEYORS
WATER RESERVOIR
B
C
D
E
F
G
H
J
K
L
M
O
R
S
N
CONTOUR INTERVAL: 5 FEET
SCALE : FEET
200 0 200 400 600 800

NOTE: SINGLE RETORT PHASE
FACILITY IN SOLID BLACK

Figure 2-3. Phase II process area plot plan (WRSP, 1976a).

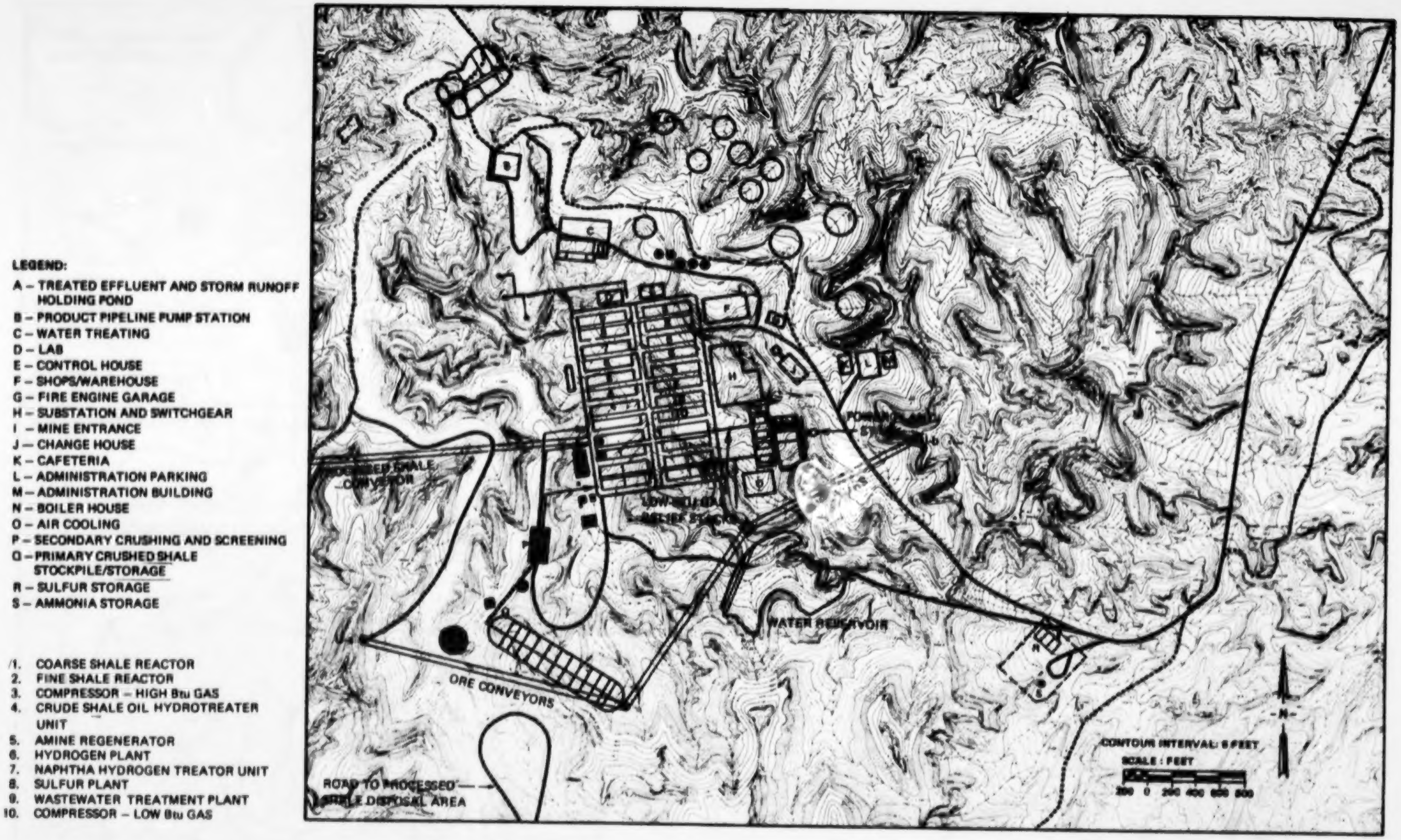

LEGEND:
A – TREATED EFFLUENT AND STORM RUNOFF HOLDING POND
B – PRODUCT PIPELINE PUMP STATION
C – WATER TREATING
D – LAB
E – CONTROL HOUSE
F – SHOPS/WAREHOUSE
G – FIRE ENGINE GARAGE
H – SUBSTATION AND SWITCHGEAR
I – MINE ENTRANCE
J – CHANGE HOUSE
K – CAFETERIA
L – ADMINISTRATION PARKING
M – ADMINISTRATION BUILDING
N – BOILER HOUSE
O – AIR COOLING
P – SECONDARY CRUSHING AND SCREENING
Q – PRIMARY CRUSHED SHALE STOCKPILE/STORAGE
R – SULFUR STORAGE
S – AMMONIA STORAGE
1. COARSE SHALE REACTOR
2. FINE SHALE REACTOR
3. COMPRESSOR – HIGH Btu GAS
4. CRUDE SHALE OIL HYDROTREATER UNIT
5. AMINE REGENERATOR
6. HYDROGEN PLANT
7. NAPHTHA HYDROGEN TREATOR UNIT
8. SULFUR PLANT
9. WASTEWATER TREATMENT PLANT
10. COMPRESSOR – LOW Btu GAS
CRUSHED SHALE CONVEYOR
WATER RESERVOIR
ORE CONVEYORS
ROAD TO PROCESSED SHALE DISPOSAL AREA
CONTOUR INTERVAL: 5 FEET
SCALE : FEET
200 0 200 400 600 800
N

Figure 2-4. Process area plot plan, Phases III and IV (WRSP, 1976a).

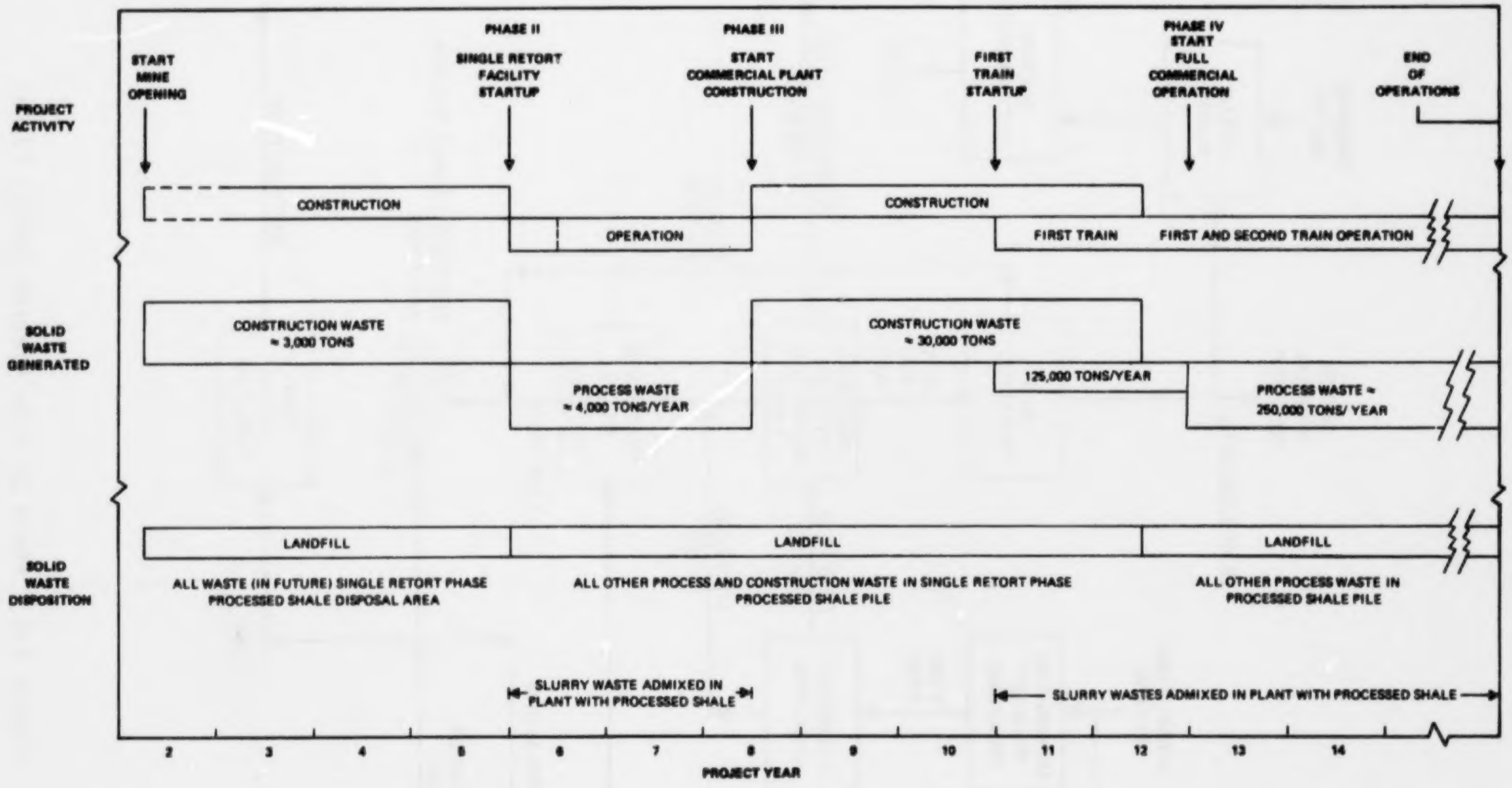

PROJECT ACTIVITY
SOLID WASTE GENERATED
SOLID WASTE DISPOSITION
START MINE OPENING
PHASE II SINGLE RETORT FACILITY STARTUP
PHASE III START COMMERCIAL PLANT CONSTRUCTION
FIRST TRAIN STARTUP
PHASE IV START FULL COMMERCIAL OPERATION
END OF OPERATIONS
CONSTRUCTION
OPERATION
CONSTRUCTION
FIRST TRAIN
FIRST AND SECOND TRAIN OPERATION
CONSTRUCTION WASTE ≈ 3,000 TONS
PROCESS WASTE ≈ 4,000 TONS/YEAR
CONSTRUCTION WASTE ≈ 30,000 TONS
125,000 TONS/YEAR
PROCESS WASTE ≈ 250,000 TONS/ YEAR
LANDFILL
LANDFILL
LANDFILL
ALL WASTE (IN FUTURE) SINGLE RETORT PHASE PROCESSED SHALE DISPOSAL AREA
ALL OTHER PROCESS AND CONSTRUCTION WASTE IN SINGLE RETORT PHASE PROCESSED SHALE PILE
ALL OTHER PROCESS WASTE IN PROCESSED SHALE PILE
SLURRY WASTE ADMIXED IN PLANT WITH PROCESSED SHALE
SLURRY WASTES ADMIXED IN PLANT WITH PROCESSED SHALE
2
3
4
5
6
7
8
9
10
11
12
13
14
PROJECT YEAR

Figure 2-5. Solid waste disposal schematic for White River Shale Project (1976a).

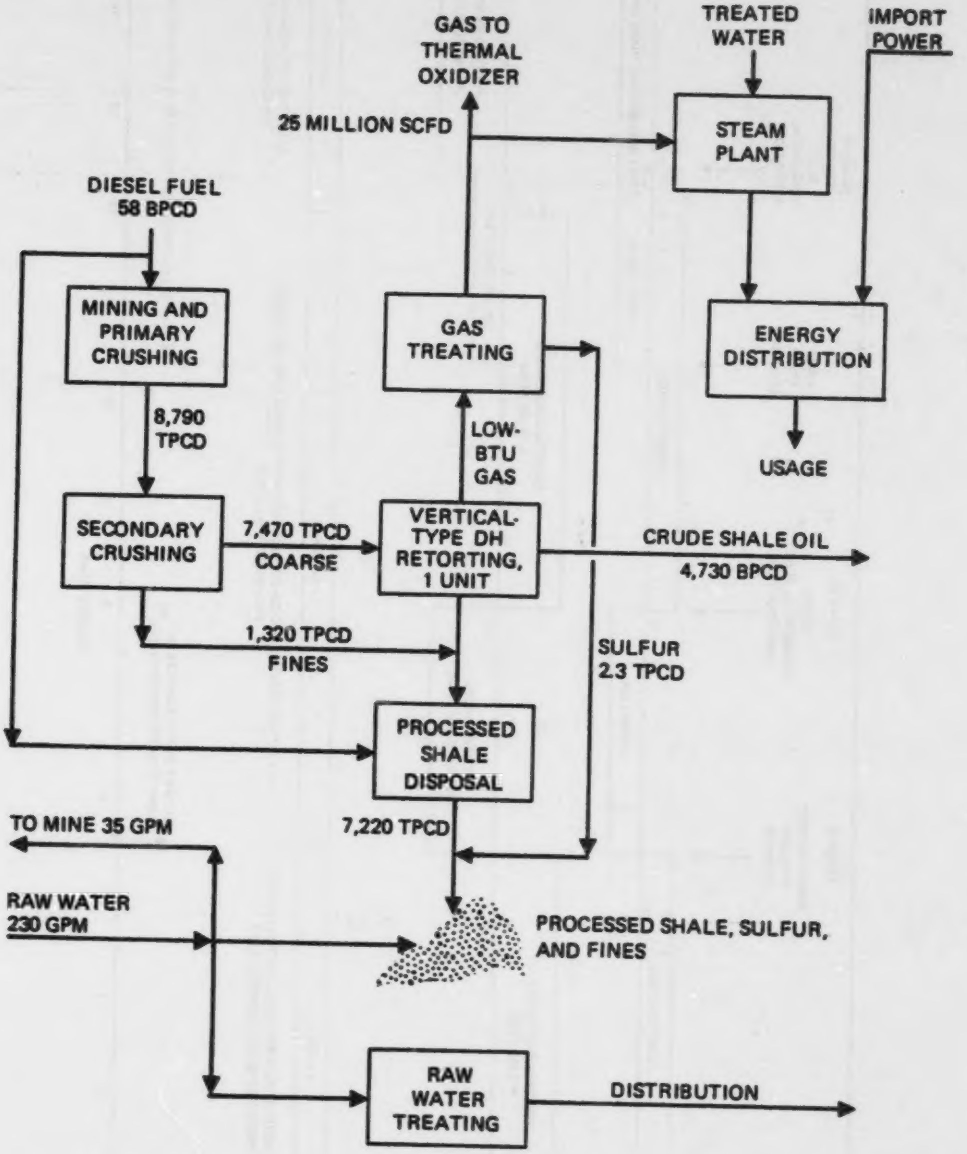

GAS TO THERMAL OXIDIZER
TREATED WATER
IMPORT POWER
25 MILLION SCFD
STEAM PLANT
DIESEL FUEL 58 BPCD
MINING AND PRIMARY CRUSHING
GAS TREATING
ENERGY DISTRIBUTION
8,790 TPCD
LOW-BTU GAS
USAGE
SECONDARY CRUSHING
7,470 TPCD
COARSE
VERTICAL-TYPE DH RETORTING, 1 UNIT
CRUDE SHALE OIL
4,730 BPCD
1,320 TPCD
FINES
SULFUR 2.3 TPCD
PROCESSED SHALE DISPOSAL
TO MINE 35 GPM
7,220 TPCD
RAW WATER 230 GPM
PROCESSED SHALE, SULFUR, AND FINES
RAW WATER TREATING
DISTRIBUTION

Figure 2-6. Phase II Flow Diagram (WRSP, 1976a).

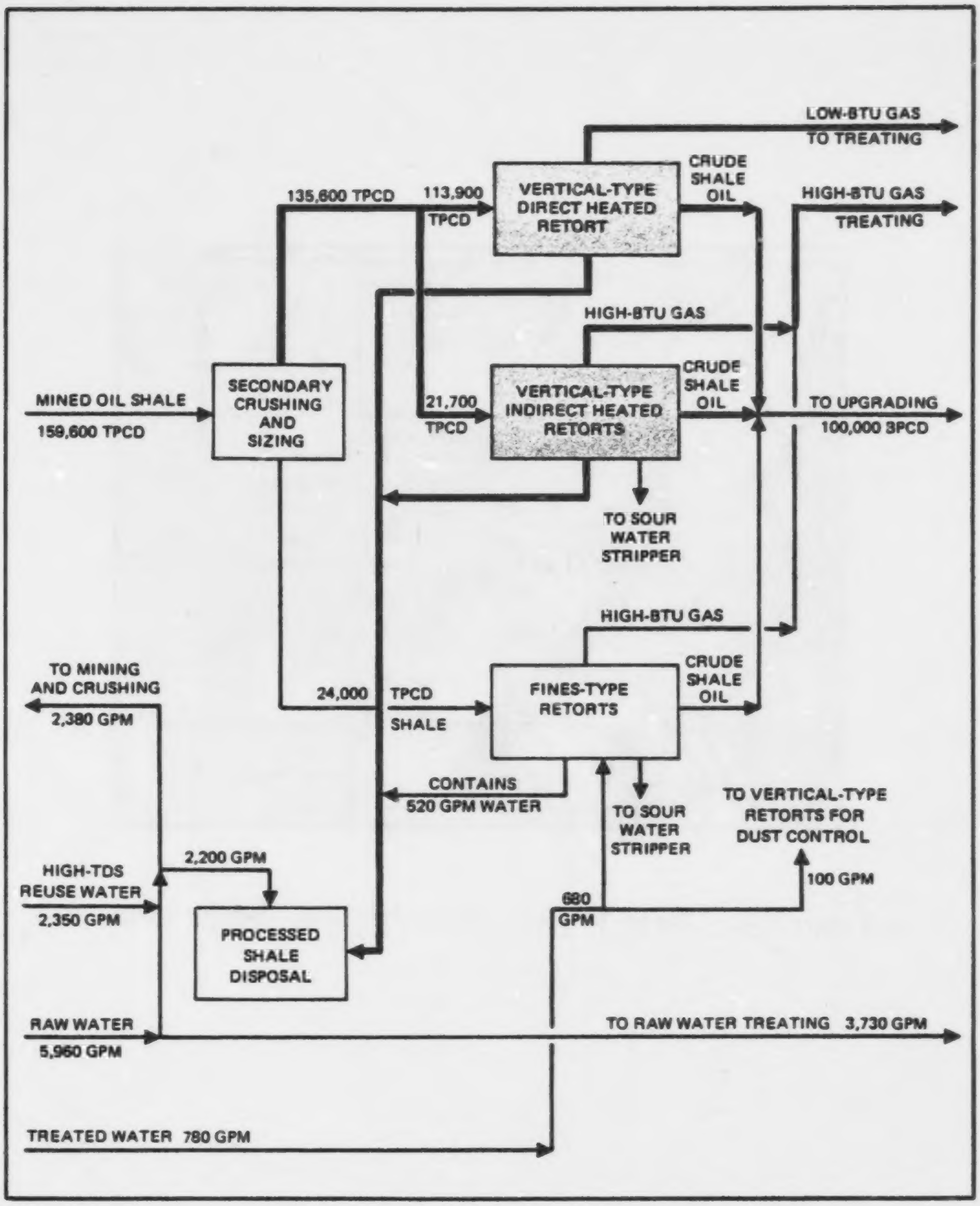

LOW-BTU GAS
TO TREATING
CRUDE
SHALE
OIL
135,600 TPCD
113,900
TPCD
VERTICAL-TYPE
DIRECT HEATED
RETORT
HIGH-BTU GAS
TREATING
HIGH-BTU GAS
CRUDE
SHALE
OIL
MINED OIL SHALE
159,600 TPCD
SECONDARY
CRUSHING
AND
SIZING
21,700
TPCD
VERTICAL-TYPE
INDIRECT HEATED
RETORTS
TO UPGRADING
100,000 BPCD
TO SOUR
WATER
STRIPPER
HIGH-BTU GAS
TO MINING
AND CRUSHING
2,380 GPM
24,000
TPCD
SHALE
FINES-TYPE
RETORTS
CRUDE
SHALE
OIL
CONTAINS
520 GPM WATER
TO SOUR
WATER
STRIPPER
TO VERTICAL-TYPE
RETORTS FOR
DUST CONTROL
100 GPM
HIGH-TDS
REUSE WATER
2,350 GPM
2,200 GPM
PROCESSED
SHALE
DISPOSAL
680
GPM
RAW WATER
5,960 GPM
TO RAW WATER TREATING 3,730 GPM
TREATED WATER 780 GPM

Figure 2-7. Phases III and IV Flow Diagram (WRSP, 1976a).

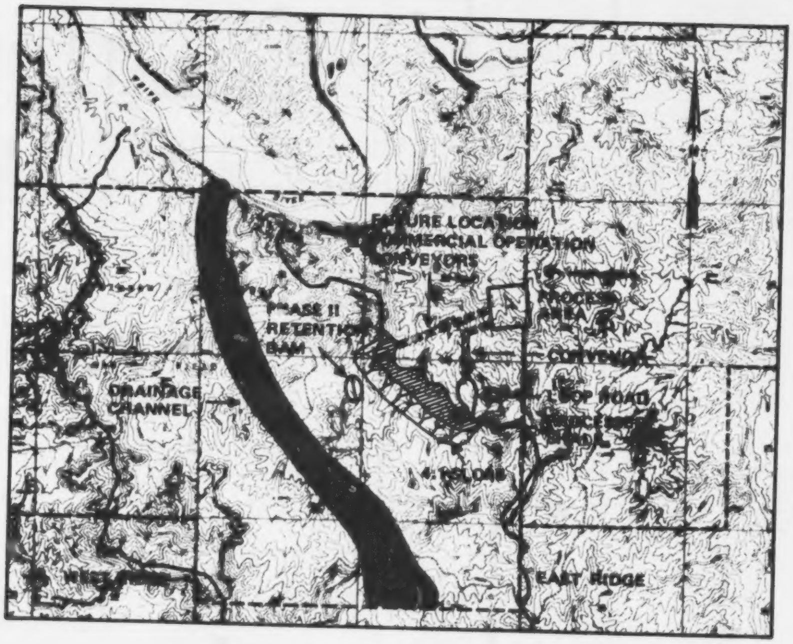

FUTURE LOCATION
COMMERCIAL OPERATION
CONVEYORS
PROCESS
AREA
PHASE II
RETENTION
DAM
CONVEYOR
DRAINAGE
CHANNEL
LOOP ROAD
EAST RIDGE

Figure 2-8. Phase II spent shale fill plan (WRSP, 1976a).

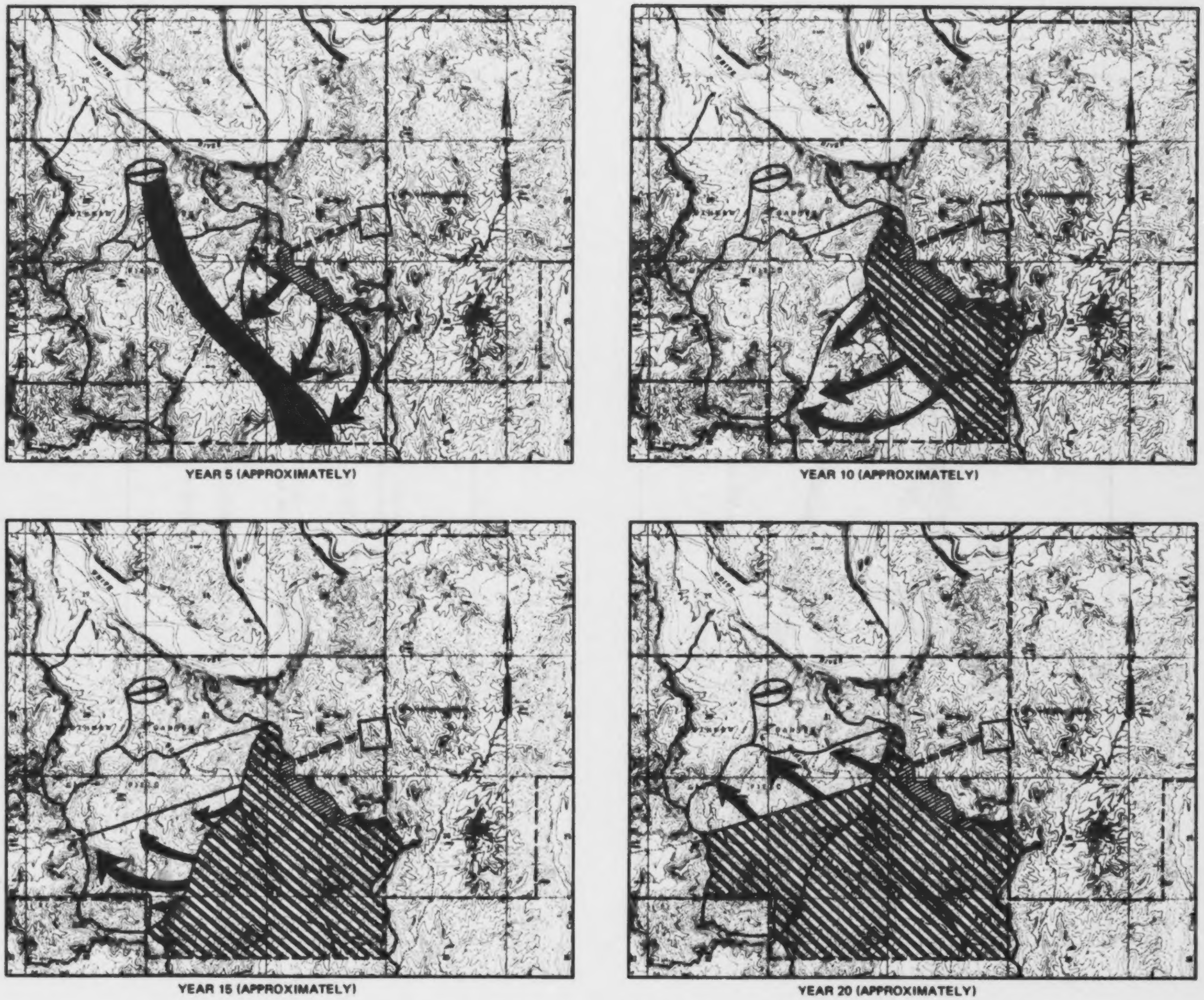

YEAR 5 (APPROXIMATELY)
YEAR 10 (APPROXIMATELY)
YEAR 15 (APPROXIMATELY)
YEAR 20 (APPROXIMATELY)

Figure 2-9. Phases III and IV spent shale fill plans (WRSP, 1976a).

Reproduced from best available copy.

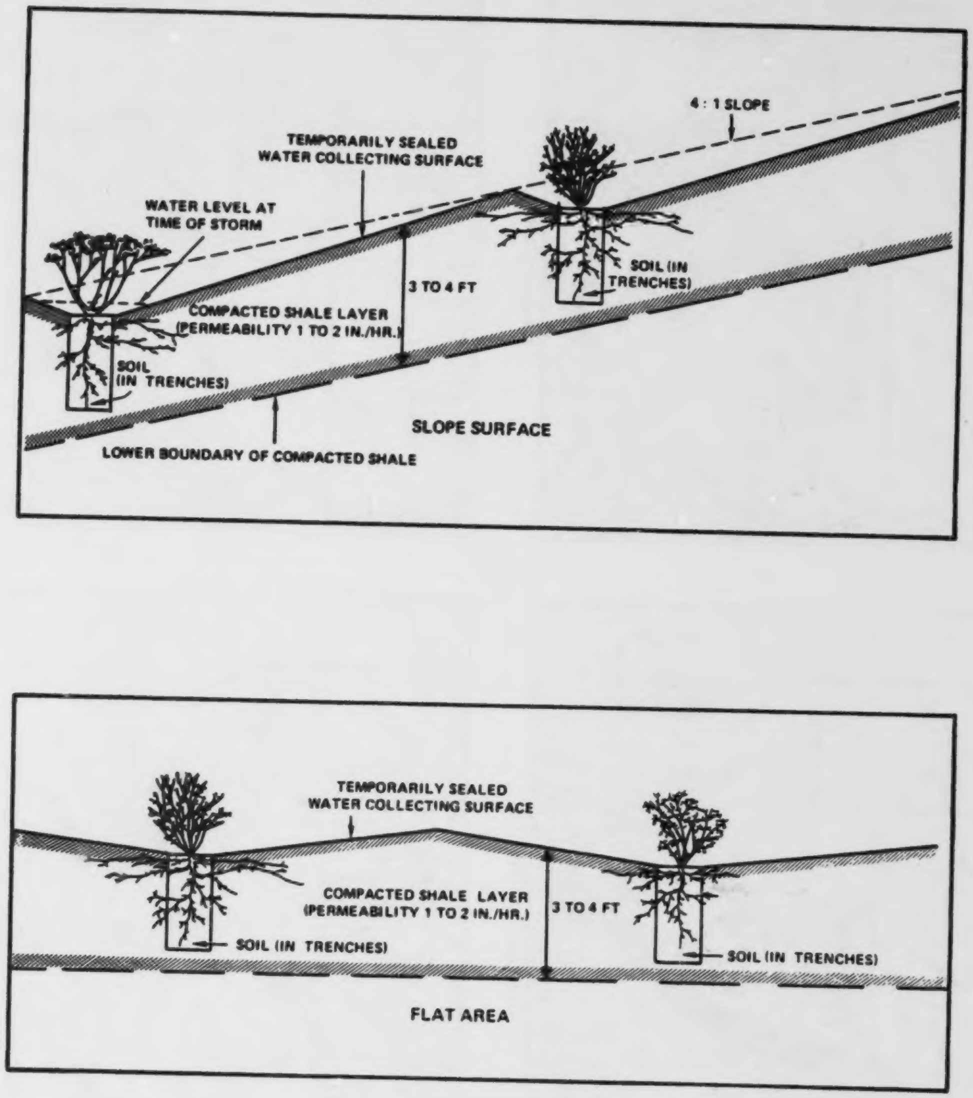

4 : 1 SLOPE
TEMPORARILY SEALED WATER COLLECTING SURFACE
WATER LEVEL AT TIME OF STORM
3 TO 4 FT
SOIL (IN TRENCHES)
COMPACTED SHALE LAYER (PERMEABILITY 1 TO 2 IN./HR.)
SOIL (IN TRENCHES)
SLOPE SURFACE
LOWER BOUNDARY OF COMPACTED SHALE
TEMPORARILY SEALED WATER COLLECTING SURFACE
COMPACTED SHALE LAYER (PERMEABILITY 1 TO 2 IN./HR.)
3 TO 4 FT
SOIL (IN TRENCHES)
SOIL (IN TRENCHES)
FLAT AREA

Figure 2-10. Surface modification and vegetation on processed shale (conceptual—not to scale) (WRSP, 1976a).

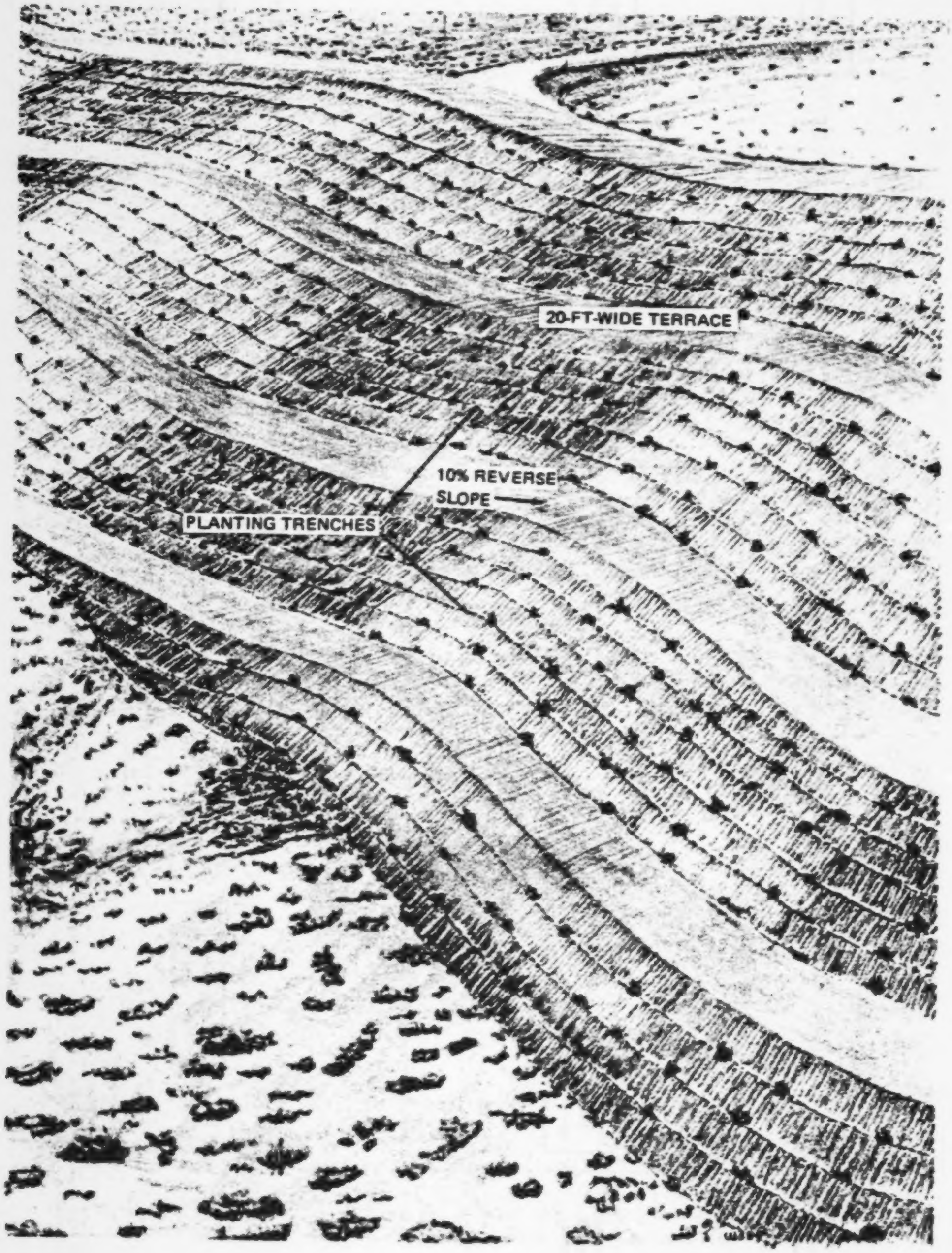

20-FT-WIDE TERRACE
10% REVERSE SLOPE
PLANTING TRENCHES

Figure 2-11. Proposed contouring of spent shale pile for revegetation (WRSP, 1976a).

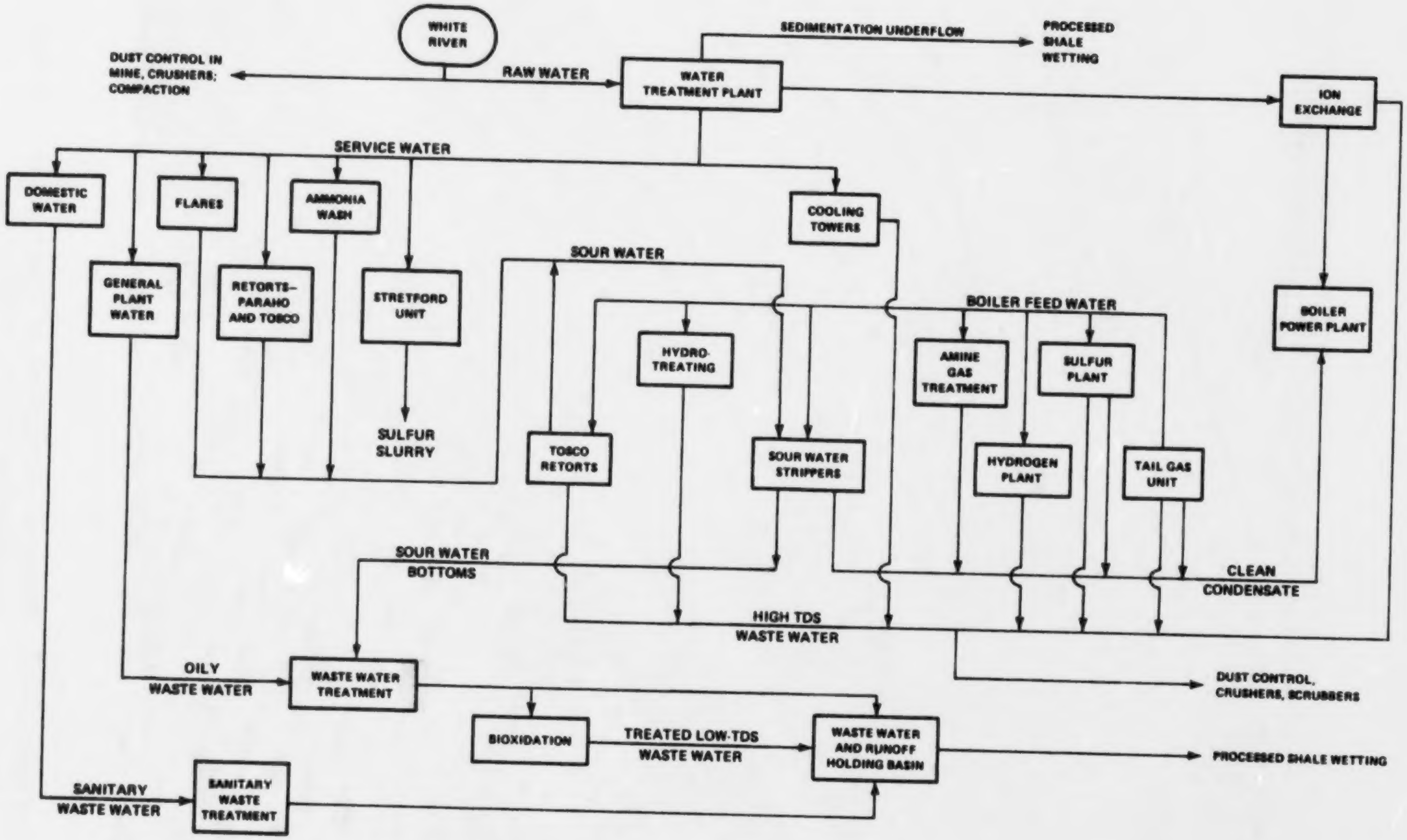

WHITE RIVER
RAW WATER
DUST CONTROL IN MINE, CRUSHERS; COMPACTION
WATER TREATMENT PLANT
SEDIMENTATION UNDERFLOW
PROCESSED SHALE WETTING
ION EXCHANGE
SERVICE WATER
DOMESTIC WATER
FLARES
AMMONIA WASH
COOLING TOWERS
GENERAL PLANT WATER
RETORTS– PARAHO AND TOSCO
STRETFORD UNIT
SULFUR SLURRY
SOUR WATER
BOILER FEED WATER
BOILER POWER PLANT
HYDRO-TREATING
AMINE GAS TREATMENT
SULFUR PLANT
TOSCO RETORTS
SOUR WATER STRIPPERS
HYDROGEN PLANT
TAIL GAS UNIT
SOUR WATER BOTTOMS
CLEAN CONDENSATE
HIGH TDS WASTE WATER
OILY WASTE WATER
WASTE WATER TREATMENT
DUST CONTROL, CRUSHERS, SCRUBBERS
BIOXIDATION
TREATED LOW-TDS WASTE WATER
WASTE WATER AND RUNOFF HOLDING BASIN
PROCESSED SHALE WETTING
SANITARY WASTE WATER
SANITARY WASTE TREATMENT

Figure 2-12. General water-use flow schematic (from WRSP, 1976a).

TABLE 2-1. PROJECTED SIZE OF DISTURBED AREAS (WRSP, 1976a)

Types of Disturbance		Single Retort (Acres)	First Train (Acres)	Two-Train (Acres)	Total (Acres)	Paved[a] and Built-Over Areas Including Dam Pools (Acres)	Areas[a] Revegetated During Operation (Acres)
Access Roads[b]		44	—	—	44	20	22
Utility Corridors[c]		11	31	—	42	—	42
Processed Shale Landfill and Conveyance[d]		130	119	2,046	2,295	7	2,183
Single Retort Phase Dam[d][e]	Dam[f]	3	—	—	3	—	3
	Pool[f]	19	—	—	19	19	—
Southam Canyon Retention Dam[e]	Dam[f]	—	6	—	6	—	5
	Pool[f]	—	35	—	35	35	—
Process Site							
Tank farm		1	14	—	15	9	—
Tank farm emergency dikes		—	23	—	23	—	23
Wastewater holding basin	Dam[f]	3	1	—	4	—	4
	Pool[f]	6	4	—	10	10	—
Freshwater reservoir[e]	Dam[f]	—	4	—	4	—	—
	Pool[f]	—	9	—	9	9	—
Process pad, roads, buildings, sulfur product shipping and NH_3 storage, etc.		26	74	—	100	75	12
Mining adits and shafts, stockpiles, changehouse, secondary crushing, etc.		8	10	1	19	16	3
Mine Vent Shafts and Excavation Landfill		—	3	<1	3	—	3
Total Disturbed Area		251	333	2,047	2,631	200	2,304

[a] Total of these columns do not agree with "Total Disturbed Area" because owing to fire hazards, some slopes may not be revegetated. Also, some areas revegetated during the single retort phase will be filled over during construction of commercial-scale units.

[b] Areas for access roads include allowances for an electric utility line.

[c] Single retort phase 6-inch freshwater pipeline includes an allowance for an electric utility line.

[d] Single retort catchment is filled over during first-train operation. Commercial operation disturbances are calculated for first-train disturbances and two-train disturbances.

[e] Pool areas for all impoundments except freshwater reservoir are maximum design areas.

[f] Dam areas indicated are the areas left exposed when maximum design pool is impounded.

TABLE 2-2. SUMMARY OF SOLID WASTES FROM COMMERCIAL MINE AND PLANT OPERATION[a]

Waste source	Type and major constituents	Approximate quantity generated		Waste collection and storage	Waste disposition
		As produced	As disposed		
Commercial mining 73,200 tonnes (80,400 tons) per day		During commercial mining for the first train, about one-half as much waste will be produced as during full commercial mining (see below). The waste sources, types, and disposition will be the same as below.			
Commercial Plant Operation 8,000 m^3(50,000 bbl) per day		During first train operation, about one-half as much waste will be produced as during full commercial plant operation (see below). The waste sources, types, and disposition will be the same as below.			
Full commercial mining; 146,300 tonnes (160,800 tons) per day					
Primary crushing	Raw shale dust (95% moisture)	36 tonnes (40 tons) per day (dry)	728 tonnes (800 tons) per day (wet) (503 1/min; 133 gal/min)	Wet scrubber and settling tank	Slurry pumped to disposal site in mine
Equipment maintenance	Waste oils	About .91 tonne (1 ton) per week		Collected in drums for salvage	Hauled to slop oil tanks for reclaiming
Shops, warehouse, and employee facilities	General trash and garbage	1.8 tonnes (2 tons) per day	1.8 tonnes (2 tons) per day	Collected in one 3.8 m^3 (5 yd^3) bin	Taken to surface and hauled by truck to landfill site for disposition
Full commercial plant operation — first and second train; 16,000 m^3 (100,000 bbl) per day					
Secondary crushing and screening	Raw shale dust (95% moisture)	109 tonnes (120 tons) (dry) per day	2,200 tonnes (2,400 tons) per day (wet) (1520 1/min; 400 gal/min)	Wet suppression and scrubber	Pumped to processed shale moisturizer; conveyed to processed shale disposal site
Raw shale feeding to vertical retorts	Raw shale dust (95% moisture)	6.2 tonnes (6.8 tons) per day (dry)	12.1 tonnes (13.3 tons) per day (wet) (83 1/min; 22 gal/min)	Wet scrubber and settling tank	Pumped to processed shale moisturizer; conveyed to processed shale disposal site
Processed shale discharge from vertical retorts	Processed shale dust (95% moisture)	5 tonnes (5.5 tons) per day (dry)	9.6 tonnes (10.5 tons) per day (wet) (7.6 1/min; 2 gal/min)	Wet scrubber and settling tank	Pumped to processed shale moisturizer; conveyed to processed shale disposal site

[a] From WRSP, 1976a

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TABLE 2-2 (continued)

Waste source	Type and major constituents	Approximate quantity generated		Waste collection and storage	Waste disposition
		As produced	As disposed		
Full commercial plant operation - first and second train; 16,000 m^3 (100,000 bbl) per day (continued)					
Raw shale feeding to fines-type	Raw shale dust (95% moisture)	2.2 tonnes (2.4 tons) per day (dry)	42.8 tonnes (47 tons) per day (wet) 30.2 l/min, 8 gal/min)	Wet scrubber and settling tank	Pumped to processed shale moisturizer; conveyed to processed shale disposal site
Fines-type retorts	Attrited alumina balls	637 tonnes (700 tons)	per day (average)	Discharged from retorts along with processed shale	Conveyed along with processed shale to processed shale disposal site
Fines-type retort preheater exhausts	Raw shale dust (95% moisture)	328 tonnes (360 tons) per day (dry)	6,534 tonnes (7,180 tons) per day (wet)	Wet scrubber and settling tank	Pumped to processed shale moisturizer; conveyed to processed shale disposal site
Fines-type retort ball elutriators	Processed shale dust (95% moisture)	27 tonnes (30 tons) per day (dry)	541 tonnes (594 tons) per day (wet)	Wet scrubber and settling tank	Pumped to processed shale moisturizer; conveyed to processed shale disposal site
Fines-type retort processed shale moisturizer exhaust	Processed shale dust (85% moisture)	1.73 tonnes (1.9 tons) per day (dry)	34.6 tonnes (38 tons) per day (wet)	Wet scrubber and settling tank	Pumped to processed shale moisturizer; conveyed to processed shale disposal site
Crude shale oil hydrotreaters	Spent HDN catalyst (nickel-based proprietary; arsenic trapped in top portion of bed)	1,183 tonnes (1,300 tons) per year (average)		Special handling procedure; transferred to air-tight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed
Naphtha hydrotreater reactor	Spend HDN catalyst (cobalt-molybdate based)	7.3 tonnes (8 tons) per year (average)		Special handling procedure; transferred to air-tight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed
Hydrogen plant	Catalyst support (Alundum balls)	76.4 tonnes (84 tons) per year (average)		Special handling procedure; transferred to air-tight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed

CONTINUED

TABLE 2-2 (continued)

Waste source	Type and major constituents	Approximate quantity generated		Waste collection and storage	Waste disposition
		As produced	Ad disposed		
Full commercial plant operation — first and second train; 16,000 m^3 (100,000 bbl) per day (continued)					
Hydrogen plant guard bed reactor	Spent guard bed catalyst (zinc sulfide-zinc oxide)	see below		Special handling procedure; transferred to airtight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed
Hydrogen plant HDS reactor	Spent HDS catalyst (cobalt-molybdate based)	see below		Special handling procedure; transferred to airtight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed
Hydrogen plant HT shift converter	Spent catalyst (iron-chromium oxides)	see below		Special handling procedure; transferred to airtight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed
Hydrogen plant LT shift converter	Spent converter catalyst (copper-zinc oxides)	see below		Special handling procedure; transferred to airtight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed
Hydrogen plant primary reformer	Spent reformer catalyst (nickel-based)	see below		Special handling procedure; transferred to airtight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed
Hydrogen plant methanator	Spent methanation catalyst (nickel-based)	see below		Special handling procedure; transferred to airtight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed
Hydrogen plant	Total spent catalysts	296 tonnes (325 tons) per year (average)		Special handling procedure; transferred to airtight transportable container	Either hauled to landfill site, moisturized, spread, and covered; or reclaimed

CONTINUED

TABLE 2-2 (continued)

Waste source	Type and major constituents	Approximate quantity generated		Waste collection and storage	Waste disposition
		As produced	As disposed		
Hydrogen plant Benfield solution filter	Deactivated carbon filter cake (adsorbed hydrocarbons)	24.6 tonnes (27 tons) per year (average)		Drained and dumped into liquid-tight transportable containers	Hauled to landfill site, moisturized, spread, and covered
Sulfur plant Claus unit reactors	Spent Claus unit catalyst (deactivated alumina)	30.9 tonnes (34 tons) per year (average)		Drained and dumped into liquid-tight transportable containers	Hauled to landfill site, moisturized, spread, and covered
Amine plant DEA filter	Diatomaceous earth filter cake (absorbed hydrocarbons)	51.9 tonnes (57 tons) per year (average)		Drained and dumped into liquid-tight transportable containers	Hauled to landfill site, moisturized, spread, and covered
Amine plant DEA filter	Deactivated carbon filter cake (adsorbed hydrocarbons)	16.4 tonnes (18 tons) per year (average)		Drained and dumped into liquid tight transportable containers	Hauled to landfill site, moisturized, spread, and covered
Shops, warehouse, employee facilities	General trash and garbage	4.6 tonnes (5 tons) per day	4.6 tonnes (5 tons) per day	Collected in one 3.8 m^3 (5 yd^3) bin	Picked up and hauled to processed shale landfill area, spread, and covered

TABLE 2-3. SUMMARY OF WASTE WATER STREAMS[a]

Wastewater stream	Source		Flow, 1/min (gal/min)		Collection	Remarks
			Phase II	Phases III and IV[b]		
Sour water	Process plant	Vertical-type IH retorts		19 (5)	Oily sewer (after stripping)	During commercial plant operation, 3,030 l/min (800 gal/min) of the stripped sour water is reused in the hydrotreating units. Net discharge to the sewer is 1,700 l/min (450 gal/min).
		Fines-type retorts		152 (40)		
		Low-Btu gas treating	57 (15)	948 (250)		
		Hydrotreating units		3,468 (915)		
		Light ends compression		72 (20)		
		Gas flares	38 (10)	72 (20)		
			95 (25)	4,730 (1,250)		
Blowdown		Fines-type retorts		72 (20)	High-TDS sewer	
		Hydrotreating units		19 (5)		
		Hydrogen plant		227 (60)		
		Sulfur plant		19 (5)		
		Tail gas units		19 (5)		
				356 (95)		
Blowdown	Utility plant	Cooling tower	19 (5)	1,743 (460)	High-TDS sewer	Steam generators will be used during Phase II.
		Power and boiler plant	19 (5)	379 (100)		
		BFW treatment		379 (100)		
			38 (10)	2,500 (660)		
Washdown	General plant area	General process area	72 (20)	1,100 (290)	Oily sewer	
Sanitary wastewater		Employee facilities	38 (10)	170 (45)	Sanitary sewer	
Contaminated storm runoff		General plant area, product pump station, and tank farms	49,350 m^3 (40 acre-feet)	55,500 m^3 (45 acre-feet)	Storm sewer, culverts, ditches	Volume for expected surface runoff during the 100-year storm.
Saline mine water	Mine	Groundwater	Nil	Nil	High-TDS sewer	If present, the stream will be used for dust control inside the mine. Any excess will be used for processed shale wetting.

[a] From WRSP , 1976a

[b] Flows during Phase II operation are projected to be about 50 percent of those expected during full commercial plant operation (Phase IV)

SECTION 3

POTENTIAL POLLUTANTS

Potential pollution sources in the study area were identified in Section 2 and methods of disposal were described. In this section, the characteristics of potential pollutants are described in detail.

POTENTIAL POLLUTANTS FROM SOLID WASTES

Construction and Mine Development

Construction of mine and processing plant facilities will be the initial source of possible pollution. A total of 162 hectares (400 acres) of land surface will be disturbed during construction. Most of the soils involved are Lithic Calciorthids (Section 5), indicating an accumulation of calcium salts. The principal anions involved are probably sulfate and carbonate. These salts, particularly sulfates which are generally more soluble than carbonates, may be leached from disturbed soils and potentially affect groundwater quality.

All of the debris produced by construction will be disposed on the site. The debris will consist largely of waste lumber, scrap metal, and excess concrete. Many of these materials are relatively inert.

Mine and Refinery Operation

Raw Shale—

The shale crushers will produce 491 tonnes (540 tons) per day of shale dust too fine to be processed by the retorts. This dust will be trapped by water sprays and pumped to the processed shale moisturizer. Although the raw shale is water repellent due to its large organic content, the dust will be a factor in possible groundwater pollution due to the large surface area of the fine dust and the fact that the dust is in intimate contact with the water during the dust control and moisturizing process. The pollutants potentially released from the raw shale may be similar to those produced from spent shale as discussed below. The relative magnitude of such releases may be substantially different from spent shale.

Spent Shale—

By sheer volume, the processed shale overwhelms all of the other possible groundwater pollutants. It is estimated (White River Shale Project, 1976a) that 725 million cubic meters (950 million cubic yards) of processed shale will be disposed of during the life of the project. The shale will be dumped in Southam Canyon on the west edge of Tract U-a, eventually filling it to a depth of 150 meters (500 feet). If water should penetrate the pile, the water would be expected to leach substantial amounts of soluble salts, trace elements, and organic compounds from the spent shale. If this leachate were to infiltrate to the groundwater, it would cause serious pollution of the aquifer.

The quality of leachate through or runoff from spent shale disposal piles is highly dependent upon the site-specific characteristics of the oil shale body and the retorting and recovery processes used. Specific information on certain spent shale characteristics for the Paraho process is not available. In the absence of these specific data, information on various retorting processes, including the U.S. Bureau of Mines Gas Combustion process, the Union Oil Company process, and the TOSCO process (which will be employed by the White River Shale Project) is presented in the following pages. The vertical direct heating kiln of the Paraho process is somewhat similar to the direct heating gas combustion kiln employed in the Bureau of Mines and Union Oil processes. Hence, the data provided may serve in the absence of process-specific data to address the question of spent shale characteristics.

The raw oil shale consists of mineral grains imbedded in a kerogen matrix. The minerals composing the grains are, in roughly descending order of abundance, quartz, dolomite, calcite, and albite (Table 3-1; Desborough et al., 1974). Because of its chemical stability, the quartz presents little pollution hazard. The calcite and dolomite, however, are soluble after release from the kerogen matrix. The albite and smaller amounts of dawsonite and nahcolite release sodium after retorting. Sulfur occurs in the kerogen and composes about 1 percent of the organic material. Sulfur in oil shale also occurs as sulfide. There is a correlation between the richness of the oil shale and the sulfide content (Desborough et al., 1974). This sulfide is oxidized during retorting, producing sulfates.

Two factors combine to give the spent oil shale a high soluble salt content: the release of salts formerly trapped in the organic matrix and the decomposition of minerals in the intense heat of retorting. It is expected that the soluble salt content will be from 6,000 to 20,000 ppm by weight (White River Shale Project, 1976). The actual figure may be on the high side of this range. Schmidt-Collerus (1974) reports salt contents of 20,000 to 50,000 ppm. If the total projected volume of retorted shale (approximately 909 million tonnes [1 billion tons]) is produced, it may contain more than 18.2 million tonnes (20 million tons) of soluble salts.

Such a high level of soluble salt is certain to give a high TDS load to any water in contact with it for even a short length of time. Typical TDS concentrations of leachates can be very high. In one experiment (Ward, 1972), the first leachate collected after percolation through a 120 cm thickness of spent shale had a TDS value of 140,000 ppm.

Several experiments have been done by various groups to determine the major ions and their concentrations in the spent shale leachate. Ward (1971)

TABLE 3-1. MAJOR MINERALS IN RAW SHALE AND OIL SHALE ASHED AT 525° C – DETERMINATIONS BY BULK X-RAY DIFFRACTOMETER ANALYSIS[a]

Sample source	Oil yield (gpt)[b]	Oil yield (l/t)[c]	Raw oil shale[d]	Oil shale ashed at 525° C
Mahogany Zone	70.7	297.5	Quartz, albite, dolomite>>calcite>>>siderite, dawsonite	Quartz, albite>>>dolomite (anhydrite)
	47.9	201.6	Quartz, dolomite>>analcite>calcite, dawsonite>albite	Quartz>>>dolomite>calcite>albite (anhydrite)
	68.8	289.6	Quartz, dolomite>>albite, analcite, calcite>>dawsonite	Quartz>>>dolomite, albite (anhydrite)
	72.0	303.0	Quartz, dolomite, albite>>>dawsonite, calcite	Quartz>albite>>>dolomite (anhydrite)
	59.6	250.9	Quartz>>dolomite>>albite, calcite	Quartz>>dolomite>albite, calcite
	35.0	147.3	Quartz, dolomite>calcite, albite	Quartz>dolomite, calcite>albite
R-4 Zone	57.9	243.7	Quartz>>dawsonite>>dolomite>K-feldspar>calcite	Quartz>>>K-feldspar, calcite (anhydrite)
	57.0	239.9	Quartz>>>dolomite>calcite, K-feldspar>dawsonite, nahcolite(?)	Quartz>>>K-feldspar, calcite>dolomite >siderite (anhydrite)
	35.0	147.3	Quartz>>>dolomite, analcite>dawsonite, K-feldspar>calcite	Quartz>>K-feldspar>>calcite, dolomite, albite, mica (anhydrite)
	58.5	246.2	Quartz>dolomite>calcite>K-feldspar, dawsonite>albite	Quartz>>K-feldspar, calcite, dolomite, siderite, albite (anhydrite)

[a] Desborough et al., 1974

[b] Gallons per ton

[c] Liters per tonne

[d] Minerals listed in order of decreasing abundance: Quartz, SiO_2; Albite, $NaAlSi_3O_8$; Dolomite, $CaMg(CO_3)_2$; Calcite, $CaCO_3$; Siderite, $FeCO_3$; Dawsonite, $Na_3Al(CO_3)_3 \cdot 2Al(OH)_3$; Analcite, $NaAlSi_2O_6 \cdot H_2O$; Nahcolite, $NaHCO_3$; K-feldspar, variable composition.

performed an experiment in which he put 100 grams of shale residue through a No. 40 sieve, mixed it with 250 ml of distilled water for 5 minutes in a blender, added 750 ml more water, filtered and analyzed. The results are summarized in Table 3-2 and show that the TOSCO, USBM, and especially the UOC spent shale, produce sodium sulfate leachate.

In another experiment, 100 grams of shale were put through a No. 40 sieve and shaken manually with 1 liter of distilled water for 5 minutes. The results are tabulated in Table 3-2. These results are similar to the TOSCO data from the blender experiment.

In a more physically realistic experiment, Ward (1971) filled a 120-cm column with 12,500 grams of TOSCO shale residue and maintained a constant head of 2 cm of distilled water. The leachate was analyzed in serial batches to reveal changes in concentration as leaching continued. The initial leachate had a TDS of 140,000 mg/l. Other data from this experiment are summarized in Table 3-2. These data show a shift in the chemical composition of the leachate over time. Initially the cations are dominated by sodium (73.7 percent of the milliequivalent total of sodium, calcium, and magnesium), while the estimated ultimate leachate water is predominantly magnesium (58.4 percent of the total sodium, calcium, and magnesium milliequivalents). The proportion of calcium also increases with time, but to a smaller extent than magnesium. Sulfate is the predominant (90 percent) anion in both the initial and ultimate leachate water.

In addition to column studies, Ward (1972) also performed snowmelt leaching studies under realistic conditions. Sixty-two tonnes (68 tons) of TOSCO shale were formed into a bed 24.4 meters (80 feet) long, 2.4 meters (8 feet) wide at the lower end, and 3.6 meters (12 feet) wide at the top, with a maximum thickness of 0.6 meter (2 feet) and a 0.75 slope. Eighteen centimeters (7 inches) of artificial snow containing 4.5 centimeters (1.75 inches) of water were sprayed on the surface. The first leachate was produced after 2 weeks and the bed was not saturated at the time. A total of 0.187 centimeter (0.073 inches) of leachate was produced. Data from this experiment are contained in Table 3-2. The initial percolation data show that the dominant anion is again sulfate, as was shown in Ward's earlier column percolation studies. However, the sodium concentration is reduced and calcium and magnesium are greater in this study; in this sense, the results are similar to samples collected midway through the earlier column studies. By contrast, calcium is the predominant cation in the runoff, and bicarbonates are relatively greater than observed in percolation samples. Additionally, the ionic composition of the runoff water is rather uniform between the initial and final samples (Figure 3-1).

Metcalf and Eddy (1975) performed similar tests. A bed with a sealed base and drains was prepared and 45.5 tonnes (50 tons) of TOSCO shale were shaped into a pile 2.4 by 7.3 meters (8 by 24 feet), 1.4 meters (4.5 feet) deep, with a 4:1 sloping foot, 2.4 by 5.5 meters (8 by 18 feet). Water was applied at the rate of 20.4 liters per square meter per hour (0.5 gal per sq ft per hour) to test the penetration of water through the pile. The results are contained in Table 3-3. Table 3-3 also contains results from a water injection test and results of runoff and leachate water quality from simulated rainfall experiments.

TABLE 3-2. RESULTS OF OIL SHALE LEACHATE WATER QUALITY EXPERIMENTS

Reference/experiment	Sample type	TDS (mg/l)	Conductivity (μmhos/cm)	K (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	HCO_3 (mg/l)	Cl (mg/l)	SO_4 (mg/l)	pH
Ward, 1971/Blender	Raw Shale	146	310	24	48	10	1.0	75	2.2	49	8.15
	USBM	1,001	1,495	72	225	42	3.5	38	13	600	7.78
	UOC	9,702	11,050	625	2,100	327	91	28	33	6,230	9.94
	TOSCO	1,115	1,750	32	165	114	27	20	7.6	730	8.40
Ward, 1971/Shaker [a]	Raw Shale	270	300	-	-	-	-	-	-	-	8.41
	USBM	970	1,320	-	-	-	-	-	-	-	7.82
	TOSCO	1,121	1,640	10	206	102	31	20	5.8	775	8.43
Ward, 1971/Column Percolation	TOSCO, 254 ml[b]	46,800[c]	78,100	-	35,200	3,150	4,720	-	3,080	90,000	-
	TOSCO, 1,060 ml	15,060[c]	25,100	-	6,900	900	1,450	-	370	21,500	-
	TOSCO, 1,600 ml	4,410[c]	7,350	-	735	585	468	-	138	4,520	-
	TOSCO, 2,500 ml	3,420[c]	5,700	-	-	-	-	-	-	-	-
	TOSCO, 4,560 ml	2,310[c]	3,850	-	-	-	-	-	-	-	-
	TOSCO, ∞ (estimated)	1,080[c]	1,800	-	86	64	118	-	11	740	-
Ward, 1972/Snow Melt Percolation	TOSCO, initial runoff	446	572	1.8	11	83	22.3	88	-	239	7.58
	TOSCO, final runoff	43	60	<0.1	0.92	9.2	1.3	13	-	18	7.89
	Initial Percolate	-	10,730	23	3,400	1,360	1,525	363	92	14,400	7.90
	Composite Percolate	-	9,630	23	3,040	1,120	1,175	358	73	11,900	7.79

[a] TDS is residue after evaporation at 103° C (others are 180° C)

[b] Total leachate volume given

[c] Estimated at 0.6 x conductivity

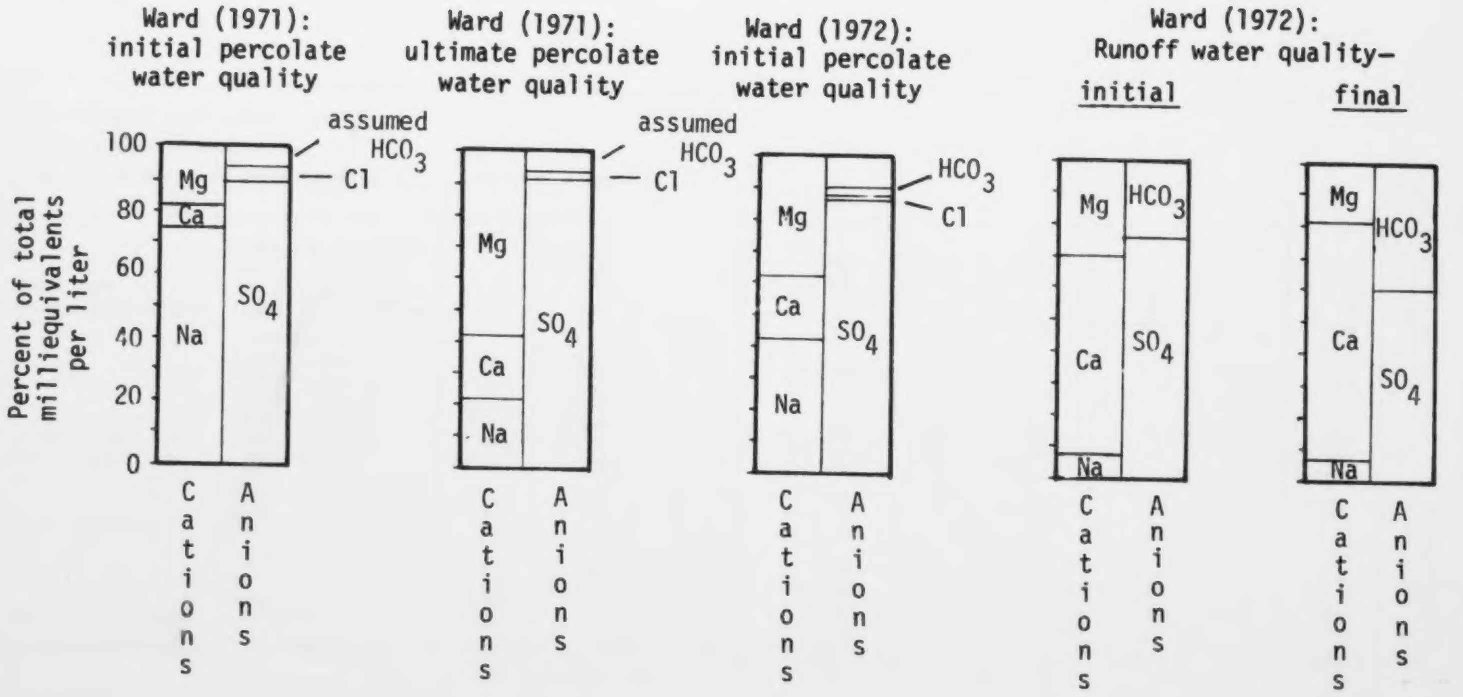


Figure 3-1. Approximate ionic composition of spent shale leachate and runoff waters (data from Ward, 1971 and 1972).

TABLE 3-3. SUMMARY OF OIL SHALE LEACHATE AND RUNOFF WATER QUALITY EXPERIMENTS

Type of test	Type of sample	Other description	TDS (mg/1)	K (mg/1)	Na (mg/1)	F (mg/1)	HCO_3 (mg/1)	Cl (mg/1)	SO_4 (mg/1)	pH
Water Penetration, Bed 1	Leachate (slope drain)[c]	Up to 0830, day 1 (5/2)[a]	29,742	74	8,510	16.4	-	-	-	2.5[b]
		0830-1620, day 1	40,568	84	9,488	-	-	-	-	2.5[b]
		1620-1820, day 1	43,771	88	10,293	17.1	-	-	-	2.5[b]
		1820, day 1 — 0800, day 2	28,425	76	7,820	-	-	-	-	2.6[b]
		0800-0900, day 2	32,793	82	9,316	16.8	-	-	-	2.6[b]
		2 hours after rain[d]	38,719	100	10,465	-	-	-	-	2.6[b]
	Leachate (deep drain)	Up to 1730, day 4	49,181	59	10,293	-	-	-	-	2.7[b]
		Up to 1930, day 5	52,725	61	10,465	15.6	-	-	-	2.7[b]
		Up to 1430, day 7	57,137	68	17,825	-	-	-	-	2.7[b]
		Initial 1730, day 38 (6/9)	48,774	82	12,650	17.2	-	-	-	-
Water Injection, Bed 2	Leachate	Mean	-	8.8	149	1.3	155[e]	192	272[f]	7.5
		(range, 5 samples)	-	(5-10)	(74-185)	(0.4-3)	(98-189)	(64-343)	(158-380)	(7.2-7.7)
Runoff and Leachate, Bed 1	Runoff	8 hours	-	6.6	82	3.2	116	6	127	7.4
		16 hours	-	6.1	50	1.8	153	3	40	8.3
		24 hours	-	6.5	48	1.8	85	3	16	8.4
		40 hours	-	6.4	48	2.3	116	3	16	8.2
		48 hours	-	6.4	48	1.5	116	2	15	8.1
		--[g]	-	7.3	63	2.1	-	4	376	7.7
		--[g]	-	6.1	57	1.2	-	3	68	8.0
		--[g]	-	6.1	57	1.5	-	3	28	8.1
		--	-	5.8	55	1.2	-	3	24	8.2
		--[g]	-	6.1	55	1.0	-	3	13	8.2
	Leachate	Mean	-	110	10,370	12.9	-	-	30,270[h]	2.6[b]
		(range) (n=12)	-	(79-140)	(9,050-12,750)	(5.2-17.5)	-	-	(29,110-31,120)	(2.4-4.8)

[a] Data are for cumulative volumes collected in indicated time frame; volumes collected not reported

[b] Samples were alkaline when collected but underwent pH reversal during storage

[c] Slope drain was that beneath sloped portion of shale bed; deep drain was located beneath level portion of bed

[d] Total water collected in 2-hour period after artificial rainfall was halted

[e] Three samples collected

[f] Four samples collected

[g] Time unspecified

[h] N=4

All of these analyses demonstrate that both the concentration and the quality of spent shale leachate can change dramatically with time. In Figures 3-2 and 3-3, the results of Ward's column studies are plotted. The values of TDS decrease from an initial high of 140,000 mg/l to around 1,000 mg/l equilibrium value (calculated). The water quality shifts from a sodium sulfate water to a sodium-calcium-magnesium sulfate water. This change can be explained by a rapid leaching of the more soluble nahcolite and sodium and sulfate created during retorting, leaving a residue of dolomite and calcite which is less soluble than these other materials. Thus leaching from spent shale disposal piles would result in an initial pulse of highly concentrated (sodium sulfate) waters which would change eventually to lower concentration hard water leachate.

In addition to long-term changes in leachate composition, there are rapid character changes after it is exposed to air. When it emerges from the shale pile, it is yellow, with a pH of 8 to 9. In a few weeks the color changes to blue and the pH to 2 or 3 (Metcalf and Eddy, 1975). The pH change is ascribed to the oxidation of sulfides and polythionates, and the color change to the reduction of hexavalent molybdenum blue complex.

Major ions are not the only source of potential groundwater pollution from the oil shale residues. The spent shale also contains varying amounts of a great variety of trace elements. Table 3-4 lists measured concentrations of various trace elements in raw oil shale and trace elements in shale retorted by both the direct and indirect modes of the Paraho process. Data on concentrations in raw and processed shale may be compared if changes in density (mass per unit volume) during retorting are considered.

Many of these trace elements are readily soluble in water. In Table 3-5, Ward lists the maximum observed concentrations of a number of minor elements. He notes that maximum concentrations in runoff would be less than these reported values, but this is not true for leachate; in fact, they might well be higher. Table 3-6 is a compilation of trace analyses of leachate from five penetration studies by Metcalf and Eddy (1975) using TOSCO shale residue.

As indicated in the preceding discussion, potential releases of inorganic salts from raw and spent shale pose a substantial risk of water quality degradation. Organic compounds created during the retorting process are also important potential pollutants. All of the carbon compounds in the raw shale are not volatilized if the heat of retorting is below 1,200° C (2,192° F). Below this temperature, between 2 and 5 percent of the organic carbon will remain on the spent shale (Schmidt-Collerus, 1974). The TOSCO II shale residue contains 4.5 percent by weight (45,000 ppm) organic carbon (Whitcombe and Vawter, 1976), and the Paraho residue contains 3 percent (30,000 ppm) (Schmidt-Collerus et al., 1976). Data listed in Table 3-7 provide some indication of the potential for leaching of organics from spent shale. Because of the high total organic carbon (TOC) content of the water added in these experiments, the amount of material leached from the spent shale is difficult to address from these data. However, these data (Table 3-7) do indicate that overall attenuating of organic levels, as retort waters leach through spent shale, may not be great, as the TOC level added in the retort water (mass TOC per unit mass spent shale) is comparable to the TOC in the resulting leachate water.

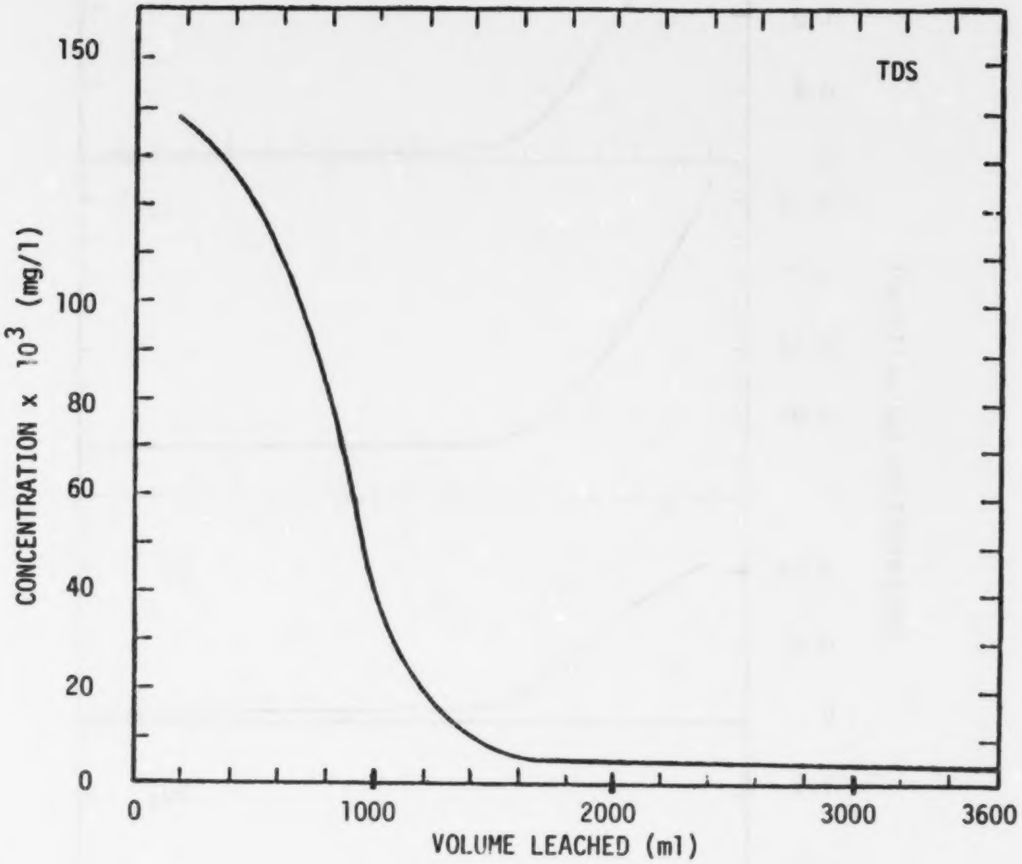


Figure 3-2. Observed changes in total dissolved solids (TDS) concentration versus volume of water leached through spent oil shale (Ward, 1971).

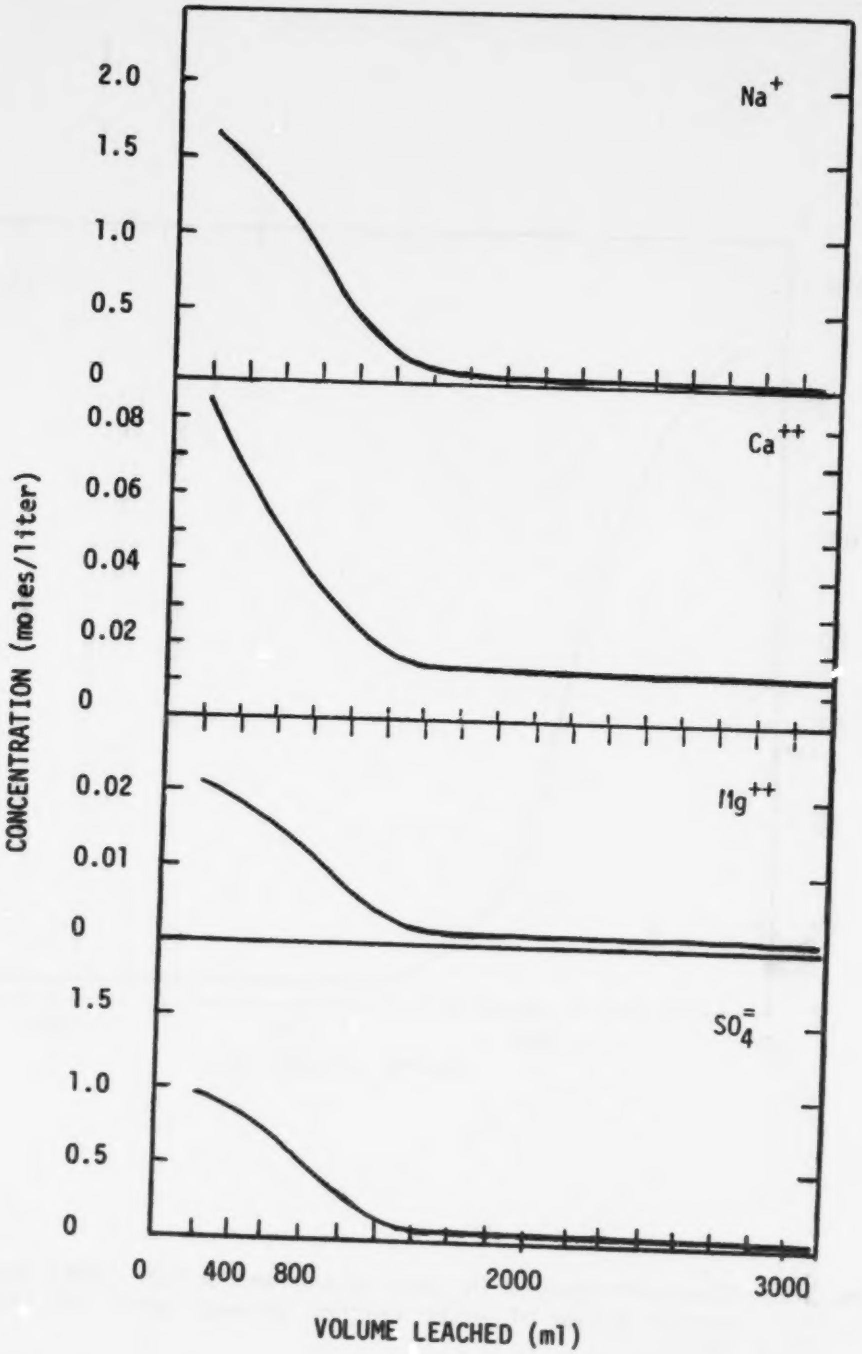


Figure 3-3. Observed changes in concentrations of sodium (Na), calcium (Ca), magnesium (Mg), and sulfate (SO_4) versus volume of water leached through spent oil shale (Ward, 1971).

TABLE 3-4. TRACE ELEMENT CONCENTRATIONS (ppm) IN RAW OIL SHALE AND SPENT SHALE FROM PARAHO DIRECT HEATING MODES

	Concentration (ppm)		
Constituent	Raw Shale[a]	Pilot plant Paraho Direct mode[b,c]	Semiworks Paraho Direct mode[b,c]
Arsenic	40	35	18
Barium	410	180	310
Cadmium	<0.8[d]	<0.2	<0.2
Chromium	40	230	110
Lead	34.7	23	24
Mercury	0.47[e]	0.06	0.06
Selenium	1.7	0.5	0.4
Silver	-	<0.2	<0.2
Fluoride	1,290	>1,000	920
Uranium	-	5	7
Thorium	-	7	4
Cesium	-	6	10
Iodine	-	<0.2	<0.2
Tin	-	0.2	2
Molybdenum	23	14	18
Strontium	306	970	760
Bromine	-	0.2	0.2
Copper	59	57	53
Nickel	29	75	20
Cobalt	10	19	15
Manganese	234	800	700
Vanadium	132	180	110
Chlorine	0	43	42
Boron	104	48	82
Beryllium	-	2	1
Lithium	83	85	370
Terbium	-	0.7	0.6
Gadolinium	-	1	0.9
Europium	-	0.7	0.6
Samarium	-	2	1
Neodymium	-	6	9
Praseodymium	-	2	5
Cerium	-	59	100
Lanthanum	43[j]	21	33
Antimony	2.4	0.7	1
Niobium	-	7	8
Zirconium	52	65	41
Yttrium	10[h]	40	17
Rubidium	-	110	85
Germanium	-	0.9	<0.2
Gallium	9.4[g]	17	13
Scandium	6.3[f]	26	20
Titanium	1,330	>1,000	>1,000
Zinc	84	22	17

[a] Mean of 10 samples from Mahogany bed and R-4 zone (Desborough et al., 1974)
[b] TRW, 1977
[c] Iron, calcium, potassium, sulfur, phosphorus, silica, aluminum, magnesium, and sodium all present in quantities >1,000 ppm
[d] Maximum concentration observed = 1.2 ppm
[e] n=8; maximum concentration observed = 2.9 ppm
[f] n=8
[g] n=9
[h] n=4
[j] n=5

TABLE 3-5. CONCENTRATIONS OF MINOR CONSTITUENTS IN RAW AND SPENT SHALE LEACHATE[a]

Ion	Maximum concentration observed (mg/l)	Source	Test
Al^{+++}	2.5	TOSCO	column (first leachate)
Ba^{++}	4.0	Raw	blender
Br^{-}	<0.1	--	--
Cu^{++}	<0.1	--	--
Cr^{+6}	<0.1	--	--
F^{-}	3.4	UOC	blender
Fe^{+++}	1.7	TOSCO	column (first leachate)
I^{-}	0.16	--	--
Mn^{++}	<0.1	--	--
Pb^{++}	<0.1	TOSCO	column (first leachate)
Zn^{++}	2.5	TOSCO	column (first leachate)

[a] Ward, 1971

TABLE 3-6. RESULTS OF TRACE METAL ANALYSIS OF PROCESSED SHALE LEACHATE FROM FIVE WATER PENETRATION STUDIES[a]

Element	Concentration (ppm)		
	Maximum	Minimum	Mean
Mercury	0.005	$<3\times10^{-6}$	0.0016
Lead	0.004	<0.001	0.0021
Cadmium	0.006	<0.001	0.0012
Strontium	6	0.6	4.52
Arsenic	0.2	0.02	0.044
Copper	0.2	0.06	0.116
Fluorine	12	0.006	3.8
Lithium	0.8	0.007	0.237
Selenium	2	0.002	1.01
Zinc	3	0.9	1.58

[a] Metcalf and Eddy, 1975

TABLE 3-7. LEACHING OF SOLUBLE MATERIAL FROM PROCESSED SHALE MOISTURIZED WITH RETORT WATER[a]

	Dilution of retort water[b]			
	4:1		2.5:1	
Shale sample size (g)	500	1,000	500	1,000
Total water applied (ml)	1,250	2,500	1,250	2,500
Leachate recovered (ml)	1,100	2,245	1,110	2,285
Water recovery (%)	88.0	89.8	88.8	91.4
TOC in water added				
(kg/tonne shale)	0.19	0.19	0.30	0.30
(lb/ton shale)	0.37	0.37	0.60	0.60
TOC in dry shale				
(kg/tonne shale)	0.13	0.13	0.13	0.13
(lb/ton shale)	0.26	0.26	0.26	0.26
TOC in leachate				
(kg/tonne shale)	0.17	0.19	0.20	0.26
(lb/ton shale)	0.33	0.37	0.39	0.52
TOC leached (% of TOC in water added and dry shale)	52.4	58.7	45.3	60.5

[a] Metcalf and Eddy, 1975

[b] Retort water composition is shown in Table 3-12

The process of pyrolysis produces a great variety of organic compounds. A common approach used for analysis of organics is the measurement of the amount of material extracted using various organic solvents such as benzene (Table 3-8).

TABLE 3-8. BENZENE-EXTRACTABLE ORGANIC MATTER FROM SPENT SHALE[a]

Sample description	Sample weight (g)	Sample moisture content (%)	Weight of extracted solubles (g)	Percent weight of solubles	
				% wet wt	% dry wt
Spent shale stored in sealed drums for 7 years	1,135.5	10.0	0.2090	0.018	0.020
	1,866.0	10.2	0.2648	0.014	0.014
	2,000.0	10.6	0.1387	0.007	0.008
	765.0	4.4	0.0497	0.007	0.007
	400.0	4.4	0.0232	0.006	0.006
	800.0	4.4	0.0736	0.009	0.011
Spent shale from pile 6 months old	2,000.0	1.4	4.4472	0.222	0.226
	2,000.0	1.6	4.6510	0.232	0.236
	2,000.0	1.6	5.0703	0.254	0.258
Six-year-old spent shale from Bureau of Mines Anvil Points operation	1,600.0	1.1	5.0734	0.254	0.256

[a] Schmidt-Collerus, 1974

Typically, spent shales may contain 200 to 2,000 ppm benzene-soluble organics. USBM spent shale has an average of 2,560 mg/l benzene solubles, and TOSCO spent shales vary from 70 to 2,600 ppm (Schmidt-Collerus, 1974). The 70 ppm figure was from TOSCO shale that had been sealed in barrels for 7 years. Some oxidation of the carbon compounds may have occurred. In contrast, pristine soils from the Piceance Basin contain 74 to 593 ppm benzene-soluble extracts (Schmidt-Collerus, 1974). In general, spent oil shales contain two to three orders of magnitude higher concentrations of benzene-soluble organics (Schmidt-Collerus et al., 1976). Assuming a benzene-soluble organic level of 2,500 ppm in spent shale, the approximately 86,000 tonnes (95,000 tons) per day spent shale produced by the White River Shale Project during Phase IV would contain over 180 tonnes (200 tons) per day benzene-soluble organics. In order to assess the environmental hazard posed by the presence of these organic constituents, the evaluation of their mobility in the environment of the spent shale disposal area must be considered as well as the mass loading to surface streams or groundwater resulting from this mobility (see Sections 7, 8, and 9).

One problem of concern is the possible carcinogenicity of components of the organic complex of the oil shale residues. One large group of organic compounds is known as polycyclic organic materials (POM) (Figure 3-4).

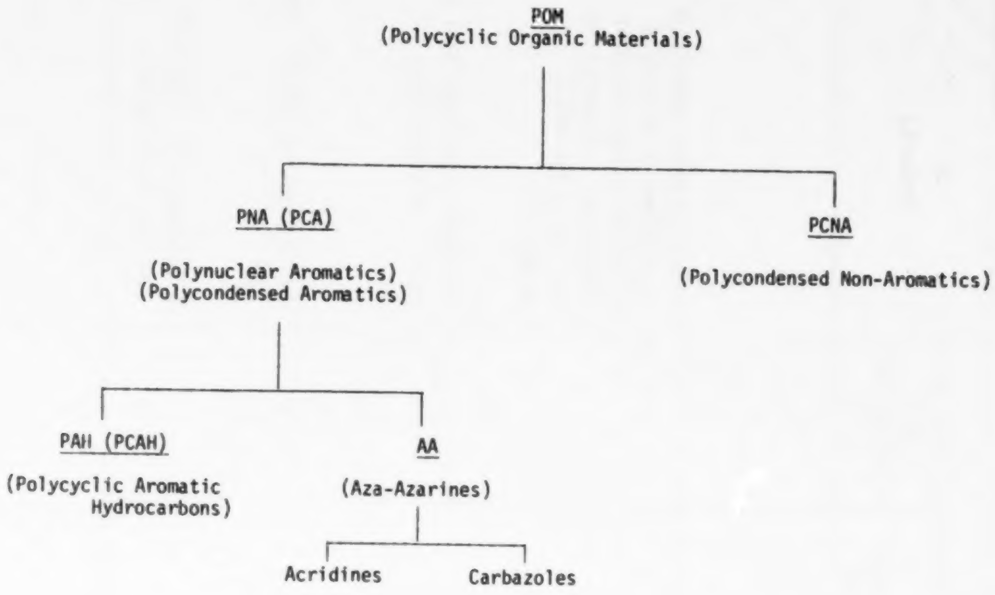

POM
(Polycyclic Organic Materials)
PNA (PCA)
(Polynuclear Aromatics)
(Polycondensed Aromatics)
PCNA
(Polycondensed Non-Aromatics)
PAH (PCAH)
(Polycyclic Aromatic Hydrocarbons)
AA
(Aza-Azarines)
Acridines
Carbazoles

Figure 3-4. Classification of polycyclic organic materials (Schmidt-Collerus, 1974).

A subgroup, the polynuclear (or polycondensed) aromatics (POM) (PNA or PCA), is known to include carcinogens. Table 3-9 contains a list of PCA's that have been detected in oil shale residues. The PNA's that have been proven to have carcinogenic effects are polycyclic aromatic hydrocarbons (PAH) and aza-azarines (AA), and in particular benzo(a)pyrene (BaP), a PAH. Table 3-10 illustrates the potential carcinogenicity of compounds identified in benzene extracts of oil shale residue. PAH compounds are known to occur in naturally growing organisms, but only in minute amounts. The shale residues contain about three orders of magnitude more PAH than natural soils. Schmidt-Collerus (1974) states that a 20 mg/l solution of BaP painted three times weekly on C3H mice produced tumors with a mean appearance time of 48 weeks. BaP is just one of several known carcinogens that have been identified in the shale residues.

The water solubility of POM's is generally proportional to the carcinogenicity. Schmidt-Collerus (1974) found that 20 to 40 percent of the total benzene-soluble organics from water-leached spent shale were contained in the shale residue, and that most of the carcinogens in the shale were dissolved and concentrated in the salt residue (see Table 3-11). The amount of carcinogenic material mobilized is increased because the salts in the leachate enhance the solubility of the POM's. Thus it may be expected that leachate from the spent shale pile will contain at least three or four times the PAH content of pristine groundwater.

TABLE 3-9. POLYCONDENSED AROMATIC HYDROCARBONS IDENTIFIED IN BENZENE EXTRACTS OF CARBONACEOUS SPENT SHALE[a]

Compound	Detection method			Remarks
	TLC[b], RB, color	Fluorescense spectrum	HPLC[c] Retention time	
phenanthrene	x	-	-	
benz(a)anthracene	x	x	x	
dibenz(a,h)anthracene	x	x	-	
7,12-dimethylbenz(a)anthracene	x	x		Fluorescence spectrum indicates a possible mixture with another compound. Separation of these by HPLC[c] in progress
fluoranthene	x	x	-	
3-methylcholanthrene	x	x	-	Further confirmation by HPLC[c] in progress
pyrene	x	-	-	
benzo(a)pyrene	x	x	x	
dibenz(c,d,j,k)pyrene	x	x	x	Separated by HPLC[c] from BaP
perylene	x	x	x	
benzo(g,h,i)perylene	x	-	-	Fluorometric identification in progress

[a] Schmidt-Collerus et al., 1976

[b] Thin-Layer Chromatography

[c] High-Pressure Liquid Chromatography

TABLE 3-10. POM COMPOUNDS IDENTIFIED IN BENZENE EXTRACT OF CARBONACEOUS SHALE COKE FROM GREEN RIVER OIL SHALE

Name of compound	Potential carcinogenity [a,b]
phenanthrene	--
fluoranthene	--
pyrene	--
anthanthrene (dibenzo[c,d,j,k]pyrene)	--
benz(a)anthracene (1,2-benzanthracene)	+
benzo(a)pyrene	+++
7,12-dimethylbenz(a)anthracene	++++
perylene	--
acridine	--
dibenz(a,j)acridine (1,2,7,8-dibenzacridine)	++
phenanthridine	?
carbazole	--
3-methylcholanthrene	++++

[a] Particulate polycyclic organic matter (from Schmidt-Collerus et al., 1976)

[b] Number of + symbols indicates increasing potential as carcinogen

TABLE 3-11. EVALUATION OF BENZO(A)PYRENE CONTENT IN SAMPLES OF BENZENE EXTRACTS FROM VARIOUS SPENT SHALE, SOILS, PLANTS, AND LEACHED SALT SAMPLES[b]

	Sample size (g)	Size of benzene-soluble fraction, BSF [g(%)]	Weight of PAH in BSF [g(%)]	Weight of BaP in BSF [g(%)]	BaP in sample (ppm)
Spent shale (6 months old)	4000 4000	9.24 (0.231) 9.24 (0.231)	3.06 (33.11)[a] 3.06 (33.11)[a]	0.000074 (0.0008) 0.000185 (0.002)	0.019 0.046
Spent shale (6 months old, water leached)	2000 2000	4.66 (0.233) 4.66 (0.233)	1.37 (29.31)[a] 1.73 (29.31)[a]	0.000093 (0.002) 0.000233 (0.005)	0.046 0.116
Spent shale (6 months old, weathered)	2000	5.12 (0.256)	1.29 (25.15)	0.000031 (0.0006)	0.015
Water soluble salts from spent shale	50	0.09 (0.188)	- (-)	0.000001 (0.0011)	0.0002
Soil from Middle Fork, Parachute Creek, Colorado	1097	0.32 (0.029)	0.05 (16.70)	0.000001 (0.0002)	0.0000337
Artemesia canis (sage plant)	200	10.20 (5.10)	- (-)	0.000010 (0.0001)	0.00059

[a] On sulfur-free basis

[b] Schmidt-Collerus, 1974

When the amount of spent shale to be produced is taken into consideration, the scale of the problem is enormous. At full 16,000 cubic meters (100,000 barrels) per day production, the operation could produce 1.6 million tonnes (1.8 million tons) of carbonaceous material and over 91,000 tonnes (100,000 tons) of benzene-soluble organics per year. If process water is used to moisten the shale, up to 364,000 tonnes (400,000 tons) of benzene-soluble organic compounds could be produced per year and disposed of in the spent shale pile.

Revegetation—

Aspects of the revegetation plans that may result in pollutant releases include spreading of native soils, the use of sewage sludge as a soil amendment/fertilizer, and potential use of additional fertilizers. The potential for leaching of calcium salts from native soils was presented earlier as part of the discussion of surface disturbance during construction. Possible pollutants from the use of sewage sludge and fertilizers are organic, phosphates, and nitrates.

Oil Upgrading—

A great variety of spent catalysts and clogged filters are planned for disposal in the spent shale pile. The largest single item is the 1,182 tonnes (1,300 tons) per year of spent hydrogenation-denitrogenation (HDN) catalyst from the naphtha hydrotreater reactor. The composition of HDN is proprietary, but it is nickel-based and the spent catalyst also contains arsenic. Each year the hydrogen plant will use about 295 tonnes (325 tons) of various other catalysts, which are largely composed of iron, copper, nickel, zinc oxides, zinc sulfides, and cobalt molybdate. In addition, the hydrogen plant and the amine plant will discard about 124 tonnes (136 tons) per year of deactivated carbon and diatomaceous earth filters containing adsorbed hydrocarbons. It is possible that some of the hydrocarbons may be phenolics and potential carcinogenic compounds.

Miscellaneous Solid Wastes—

The operation of the completed mine and processing plant will produce many kinds of solid waste. Employee facilities will generate garbage to be deposited in sanitary landfills in the spent shale pile. Typical landfill leachate pollutants are nitrates, sulfides, and iron and heavy metals. These solid wastes will be included within the spent shale pile, so production of consequential amounts of leachate will be dependent upon movement of water through the pile. Landfill leaching will be a source of concern only in conjunction with leaching of the spent shale pile and not as a separate problem.

The sludge generated by the sanitary waste treatment plant will be stockpiled and used as fertilizer for the revegetation of the spent shale pile. The areas undergoing revegetation will have to be irrigated in the initial stages, and organic pollutants could be leached from the sewage sludge and from other fertilizers and infiltrate through the shale pile to the groundwater. The principal pollutants in such a situation would be nitrates and phosphates.

The TOSCO II shale retorts use heated alumina balls to pyrolize the shale. About 640 tonnes (700 tons) per year of these balls will be discarded due to wear, and these will be disposed in the shale pile. They should not present a groundwater pollution threat, as they are relatively inert.

POTENTIAL POLLUTANTS FROM LIQUID WASTES

Construction and Mine Development

During construction and mine development, the major liquid wastes generated will be waste oils. Approximately 0.9 tonne (1 ton) of such wastes per week will be collected in drums and periodicaly hauled off-tract for reclaiming or disposal. Spillage during transfer and stockpiling may result.

Sanitary facilities will consist of chemical toilets during construction. Spillage during servicing or moving of these temporary facilities may occur, but should be minor.

Mine and Refinery Operation

Retorting and Related Facilities—

Some of the retort process water will be used directly to moisten the spent shale and some will be treated in the sour water stripper and reused. The sour water stripper bottoms will be used to moisten the spent shale. Tables 3-12 through 3-14 contain analyses of TOSCO and Paraho process water. General ranges of major constituents, in milligrams per liter, are: bicarbonate, 500 to 31,000; carbonate, 500 to 30,000; chloride, 0 to 1,300; arsenic, 0 to 1.0; ammonia, 10 to 13,000; nitrate, 0.02 to 300; phenol, 42 to 390.

In addition to the normal organic and inorganic contaminants, the process water contains 15,000 to 20,000 mg/l organic carbon, some of which is contained in POM's. Schmidt-Collerus (1974) analyzed retort process water using benzene extraction methods. The water contained 7,370 ppm benzene solubles. Since this water will be used to moisten the shale, it will increase the POM content proportionately. Schmidt-Collerus (1974) observed that if these process waters were used to moisten shale to 13 percent moisture, then for every kilogram of shale, 0.96 gram of organic matter would be added to the 2.31 grams already present, making a total of 3.27 grams (or 3,270 ppm on a dry weight basis). Hence, moisturizing spent shale with retort process water, as is proposed, will appreciably increase the potential release of organic wastes, including carcinogens.

Table 3-15 indicates the maximum and minimum expected concentrations of various pollutants in the individual process waste water streams, and gives weighted-mean calculations of the composition of the composite water used to moisten the shale.

The sour water stripper bottoms, which contain water from upgrading and refining processes as well as retort water, will have a pH of 8.5 to 9.5. They will contain 50 to 100 mg/l oil and grease, 25 to 50 mg/l ammonia, and 80 to 150 mg/l phenols, and have a chemical oxygen demand (COD) of 500 to 1,500 mg/l.

TABLE 3-12. FOUL WATER ANALYSIS, ROCKY FLATS PILOT PLANT RUN (TOSCO PROCESS)[b]

Analysis	Concentration (mg/l)[a]			
	Production day			
	1	2	3	4
Inorganics				
Total dissolved solids (organics removed)	6,660	1,980	5,940	15,300
pH	8.6	8.7	8.1	8.6
Specific conductance (μmhos per cm)	12,500	14,800	15,300	13,300
Calcium (Ca)	45	9.8	25	12
Magnesium (Mg)	<0.1	6.2	<0.1	19
Sodium (Na)	<1.0	<1.0	<1.0	<1.0
Potassium (K)	<5.0	<5.0	<5.0	<5.0
Arsenic (As)	0.07	0.09	0.08	0.06
Selenium (Se)	0.03	0.04	0.03	0.05
Molybdenum (Mo)	<1.0	<1.0	<1.0	<1.0
Lithium (Li)	<10	<10	<10	<10
Bicarbonate (HCO_3)	5,400	12,600	6,920	12,900
Carbonate (CO_3)	1,560	2,550	2,130	2,850
Chloride (Cl)	1,300	855	1,090	1,160
Fluoride (F)	<1.0	<1.0	<1.0	<1.0
Cyanide (Cn)	<0.01	<0.01	<0.01	<0.01
Silica	8	4	12	12
Nitrate (NO_3)	330	330	320	170
Phosphate (PO_4)	0.5	0.21	15.6	0.5
Ammonia (NH_3)	3,685	4,025	3,960	1,740
Total sulfur	855	1,210	775	1,240
Sulfide	848	1,200	768	1,230
Sulfate	8	8	8	8
Elemental sulfur	<1.0	<1.0	<1.0	<1.0
Organics				
Neutral oil	2,560	2,840	2,115	1,950
Amines	602	856	916	1,600
Carboxylic acids	6,480	1,680	1,215	515
Phenols	390	220	270	115
Total organic carbon	16,300	21,000	18,200	14,200
Chemical oxygen demand (COD)	24,600	31,000	27,100	23,500
5-day biochemical oxygen demand (BOD_5)	10,800	9,400	27,100	9,000

[a] Units are mg/l unless otherwise indicated. Values of pH are standard units

[b] Metcalf and Eddy, 1975

TABLE 3-13. APPROXIMATE COMPOSITION OF TOSCO II COMBINED PROCESS WASTE WATER[a]

Component	Concentration in water added to spent shale (mg/l)[b]
Inorganics	
Calcium	280
Magnesium	100
Sodium	670
Bicarbonate (HCO_3)	100
Carbonate (CO_3)	360
Sulfate (SO_4)	850
Thiosulfate (S_2O_3)	90
Chloride	570
Ammonia (NH_3)	15
Phosphate (PO_4)	5
Zinc	5
Arsenic	0.015 to 0.30
Chromium (+6)	2
Cyanide	5
Organics	
Phenols	315
Amines	410
Organic acids	1,330
Neutral oils	960
Chelate	5

[a] TRW, 1976

[b] In addition to the above, elements present in trace quantities (less than 1 ppm) are Pb, Ce, Ag, Mo, Zr, Sr, Rb, Br, Se, Cu, Ni, Co, Fe, Mn, V, Ti, K, P, Al, P, B, Li

TABLE 3-14. TRACE ELEMENT ANALYSIS OF CONDENSATE WATER AND PROCESS WATER FOR PARAHO PROCESS[a]

Element	Pilot plant cold condensate water (μg/ml) 3/10/76 0800-1700 h	Semiworks process water (μg/ml) 3/15/76 1500 h
Uranium	0.03	--
Lead	0.7	0.2
Mercury	<0.01	<0.01
Praseodymium	0.008	--
Cesium	0.01	0.01
Lanthanum	0.04	--
Barium	0.1	2.0
Iodine	0.008	--
Tin	0.05	--
Molybdenum	0.3	0.1
Zirconium	0.05	--
Yttrium	0.007	--
Strontium	0.1	3.0
Rubidium	0.4	--
Bromine	0.02	0.009
Selenium	0.04	0.1
Arsenic	0.09	1.0
Gallium	0.04	<0.02
Zinc	0.2	0.4
Copper	0.1	0.2
Nickel	0.1	0.2
Cobalt	<0.01	<0.04
Germanium	--	<0.05
Iron	>10	5.0
Manganese	0.2	0.3
Chromium	0.07	0.3
Vanadium	<0.01	0.03
Titanium	0.9	0.3
Scandium	0.01	<0.05
Calcium	8	>10
Potassium	3	>10
Chlorine	0.4	2.0
Sulfur	3	>10
Phosphorus	0.2	5.0
Silicon	4	>10
Aluminum	0.2	0.8
Magnesium	3	>10
Sodium	5	>10
Fluorine	<0.1	7
Boron	0.06	5.0
Lithium	0.02	1.0

[a] TRW, 1977

TABLE 3-15. MAXIMUM AND MINIMUM EXPECTED CONCENTRATIONS IN WASTE WATER STREAMS FOR WHITE RIVER SHALE PROJECT

Stream	TDS (mg/l)		Oil and grease (mg/l)		Phenol (mg/l)		Ammonia (mg/l)		pH (mg/l)	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Sour water bottoms	-	-	100	50	150	80	50	25	9.5	8.5
Oily water	2,000	500	1,000	50	500	50			9	7
Sanitary waste water	1,000	800	50	20	1	1	15	10	8.5	7
High TDS	10,000	5,000	-	-	-	-	-	-	8	7
Freshwater	800	400	-	-	-	-	1	1	8.5	7
Process water (in shale)	15,000	2,000	3,000	2,000	390	115	4,000	1,700	8.7	8.1
Weighted mean	7,253	2,225	880	506	124	44	989	420	8.3	7.6

The high TDS waste water stream will have a TDS of 5,000 to 10,000 mg/l. Since it is largely concentrated by simple evaporation and the source is the White River, the major ions probably would be very similar, with the addition of large amounts of nitrate from explosives.

The oily waste water stream will go through oil gravity separation and be used to moisten the spent shale. It will contain 50 to 1,000 mg/l oil and grease, 50 to 500 mg/l phenol, and 500 to 2,000 mg/l TDS. The biochemical oxygen demand (BOD) is expected to be 100 to 20,000 mg/l, and since the water comes from plant washdown, it may contain miscellaneous spilled chemicals.

Finally, sulfur slurry will be added to the spent shale. There is a possibility of sublimation of the sulfur, and of oxidation; but unless speeded by chemical reactions with percolating leachate, either process would probably be too slow to cause significant pollution.

Mine Water—

The composition of mine water is expected to be similar to that of the Bird's Nest Aquifer. The TDS of this aquifer is over 2,500 mg/l in many areas (Section 6). More detail on the quality of the groundwater is provided in Section 6. If upward leakage from the Douglas Creek Aquifer occurs, the water is somewhat less saline (approximately 850 to 1,100 mg/l TDS) than the Bird's Nest Aquifer. Other contaminants expected in mine water are similar to those described for raw shale, and they also include oil and fuel from mine machinery and explosive residues.

Explosive Residues—

The major potential pollutants from the use of ANFO explosive are nitrogen compounds, particularly ammonium nitrate.

Sanitary Wastes—

Sanitary sewage will undergo secondary treatment. It will then be used to moisten the spent shale. One potential pollutant is the organic matter remaining after secondary treatment. After typical secondary treatment, sewage will contain 10 to 20 mg/l nitrate, 5 to 10 mg/l phosphate, and 15 to 20 mg/l ammonia. Total dissolved solids are expected to range from 800 to 1,000 mg/l.

Storm Water Runoff—

Storm runoff will be diverted to the waste water holding pond and be used to moisturize the shale. Various contaminants, including soluble salts and oil and grease, may be picked up by storm runoff. These potential pollutants may be further concentrated by evaporation in the holding pond.

Stockpiles—

The variety of liquid products to be stockpiled on the tracts is listed in Section 2. These include naphtha, fuel oil, ammonia, diesel fuel, shale oil pour-point depressant, and high TDS waste water. Leakage, spills, or tank failure would release these materials. The composition of most of these wastes is self-explanatory. The composition of the high TDS waste water is derived from several sources described earlier in this subsection on liquid wastes from mine and refinery operation.

MISCELLANEOUS SOURCES AND CAUSES

Exploratory Drilling and Testing

Aquifer interchange and release at the surface are the main sources of pollution from exploration drilling and testing. Hence the potential pollutants involved are those described in Section 6 (Groundwater Quality).

Oil and Gas Wells

The same pollution mechanisms characterizing the exploration well drilling and testing program also create a potential for pollution from oil and gas wells. The potential pollutants are as referenced above.

White River Dam

The White River Dam and reservoir produce no pollutants. However, potential pollutants which may be associated with the dam and reservoir are those related to mine water and spent shale. The proposed dam and reservoir may alter the hydrogeologic framework and hence appreciably influence the mobility and effect of pollutants from these sources.

Subsidence

Subsidence and/or fissures formation produce no pollutants. However, they may significantly enhance the mobility and rate of production of pollutants associated with mine water and spent shale disposal.

SECTION 4

GROUNDWATER USE

There is no known use of groundwater from aquifers beneath the Lease Tracts. The water is of poor quality, possessing a total dissolved solids content of over 2,500 mg/l in many areas. High sodium content renders the water undesirable for agricultural use. The sulfate content exceeds recommended public health limits for human consumption. Water quality is described in more detail in Section 6.

Two oil and gas exploration wells in Asphalt Wash have been converted to stock watering wells. These wells tap the Douglas Creek Aquifer and flow at the surface. They are supposedly sealed through the Bird's Nest Aquifer, although leakage may be occurring. The water quality of the wells is intermediate between the quality of the Douglas Creek Aquifer and that of the Bird's Nest Aquifer, but the fact that the Douglas Creek Aquifer is under higher head than the Bird's Nest Aquifer indicates that leakage from the Bird's Nest Aquifer to the stock wells could not take place.

A few other stock wells to the west may tap the Bird's Nest or Douglas Creek Aquifers. Water from these aquifers is probably discharged into the Green River, or its tributaries, and thus used indirectly. It may leak upward in the center of the basin and be tapped by agricultural wells near Vernal or near the Duchesne River. These are the only known possibilities of use of groundwater from aquifers under the tracts.

As summarized above, direct use of groundwaters from aquifers below the tracts is limited. However, discharge of these aquifers to surface waters and movement through the alluvial systems tributary to the White River may indirectly influence a variety of municipal and agricultural water uses downstream in the Colorado River Basin.

SECTION 5

HYDROGEOLOGIC FRAMEWORK

The assessment of potential pollution associated with the development of Tracts U-a and U-b requires detailed knowledge of the hydrogeologic and geologic configuration of the project area. The following subsections present available information on the hydrogeologic framework. These data will be utilized in concert with proposed development information presented in Sections 2 and 3 to evaluate pollutant mobility and thus the pollution potential.

CLIMATE

The climate of the study region is typical of continental high desert areas. Summers are warm, characterized by mean daily temperatures near 27° C (80° F). Winters are cold with midwinter means below 0° C (32° F). Very low humidity results in high potential evaporation rates (99 cm; 39 inches) for the May to September period.

Precipitation is low, averaging 24.5 cm (10 inches) annually over the Tracts (Figure 5-1). About 60 percent of the precipitation takes the form of winter snow. Most of the other 40 percent occurs as summer convective rainfall (Figures 5-2 and 5-3). The precipitation in both winter and summer is related to elevation, increasing about 8.2 cm (3.2 inches) per 300-meter (984-foot) increase in altitude (WRSP, 1976b). Rainfall, however, is influenced by elevation to a greater extent than snowfall.

TOPOGRAPHY

Federal oil shale lease Tracts U-a and U-b lie between 1,500 and 1,800 meters (5,000 and 6,000 feet) above sea level. The White River occupies a narrow steep valley at the north end of the tracts (see Figure 5-4). The tracts are drained by north-south trending valleys separated by narrow mesas. The valleys drain into the White River. Erosion of outcrops is slow, but valley bottoms are occasionally quickly cut downward by flash floods. Chemical weathering has created numerous solution cavities on outcrops of the Uinta Formation. Regions underlain by the Green River Formation are characterized by gentler topography. Only where Evacuation Creek has cut a deep, narrow canyon in the Green River Formation do prominant cliffs exist.

SOILS

The soils of the tracts fall into three general groups. Most of the tract surface is covered by shallow, immature, rocky soils. The small canyon bottoms are filled with deeper, better-sorted soils. The White River and

Evacuation Creek canyons contain deeper, more mature alluvial soils. Characteristics of some representative soils are listed in Table 5-1.

The upland soils are typically very shallow, 5 to 25 cm (2 to 10 inches), and very sandy. They contain many rock fragments and are classified as flaggy loams or channery loams under the Aridisol and Entisol orders (Figure 5-5). Infiltration rates are low to very low, averaging 3.6 cm/hr (1.4 in/hr). Soil composition and texture are fairly homogeneous with depth except for the proportion of rock fragments, which increases with depth. Most of these soils are alkaline (pH 8 to 9), reflecting their calcic composition. They are derived directly from the underlying Uinta sandstone. A large part of the upland area is bare of soil and the Uinta sandstone is exposed.

The canyon-bottom soils in ephemeral stream valleys were formed by erosion from the surrounding upland. Hence, they are generally similar to the upland soils. They differ mainly in their greater depth and better sorting. They are over 150 cm (60 inches) deep in many places and up to a few tens of feet near the canyon mouths. They contain much less rock and somewhat less silt than upland soils. Canyon-bottom soils are of sandy loam texture, in the Typic Torrifluvent subgroup of the Entisol order (Figure 5-5). The better sorting results in higher infiltration rates, averaging 6.1 cm/hr (2.4 in/hr). The soil is fairly homogeneous, although in some places mud flows of a more silty texture can be distinguished. Such buried strata may restrict downward percolation.

The bottom land soils of the White River are moderately deep to very deep in the tracts area. They are well sorted and moderately fine-textured as a result of fluvial deposition. They are quite alkaline and some have exchangeable sodium percentages, lowering the infiltration rates.

The soils classifications mapped in Figure 5-5 have been reorganized into hydrologic soil types (Figure 5-6). It may be seen that most of the soils in areas where development is planned have low to very low infiltration rates. The shallowest bedrock aquifer, the Bird's Nest Aquifer, lies 185 to 215 meters (600 to 700 feet) below the land surface and the soil comprises only the first few centimeters. The rest of the overlying material is Uinta Formation sandstone, with about 18 meters (60 feet) of Green River Formation mudstone above the aquifer. Due to the impermeable nature of the Green River Formation and the numerous mudstone layers within the Uinta Formation, it does not seem likely that percolation to the Bird's Nest Aquifer could occur except through fractures or joints. Fractures and joints are not common in the Uinta Formation, and they tend to close at the mudstone layers. Percolating groundwater might, however, collect above the mudstone and migrate down dip into the alluvium of the White River. Extensive evaporite deposits resulting from seepage can be observed on the cliffs above the White River. These geologic features of the study area are discussed in the following paragraphs.

GEOLOGY

General Regional Structure

The Utah oil shale lease tracts are within the structural, depositional, and topographic region called the Uinta Basin (Figure 5-7). The basin has an area of about 18,000 km^2 (7,000 mi^2). It is bounded by the Uinta Mountains to the north and the Roan Cliffs to the south. The basin is highly asymmetric. The strata dip gently to the north from the southern edge to the base of the Uinta Mountains. From the axis of the basin to the Uinta Mountains, the dip is steep to the south. The oil shale tracts are near the middle of the gently sloping southern limb.

Regional History

A thick sequence of Mesozoic and Paleozoic sediments lies beneath the Tertiary formations exposed in the Uinta Basin. For much of the Paleozoic and Mesozoic, the area lay beneath warm epicontinental seas which deposited shales and limestones. Occasional uplift and erosion cycles resulted in thick sandstone formations. Near the end of the Cretaceous, the last of the shallow seas to cover the region began to retreat. The regressive sequence contains thick beds of alternating sand and coal deposited on the wide, swampy shores. The regression culminated in the Laramide Orogeny which lifted the Uinta Mountains for the first time.

By the Late Paleocene, the Uinta Mountains had experienced considerable erosion. The material that eroded off the Uinta Mountains and the Wasatch Mountains to the west was deposited in the fluvial Wasatch Formation. When peneplanation of the mountains was nearly complete, the large Green River Lake formed in the subsiding sedimentary basin. This lake covered both the Uinta and Piceance Basin areas and was probably continuous with the Wakashie-Bridger Lake north of the Uinta Mountains, although the location of the connecting channel is uncertain. The lake possessed an unusual longevity. Although more than 2,100 meters (7000 feet) of sediments were deposited in its center during the early and middle Eocene, it never completely dried. Frequently a large part of the lake was quite shallow, 6 meters (20 feet) or less. At times the lake extended far to the south of the present Uinta Basin and exhibited freshwater characteristics. Under adverse conditions the lake shrank and became saline. During long periods, algae were the dominant life form in the lake.

Renewed uplift and erosion in the late Eocene finally filled the lake and resulted in the fluvial siltstones and sandstones of the Uinta Formation, deposited by rivers on the floodplains and deltas adjacent to the retreating Green River Lake. At the end of the Eocene more fluvial sediments, the Duchesne Formation sandstones, were unconformably laid on the Uinta Formation. Since that time little sedimentation has taken place, except for outwash fans below the Uinta Mountains, the product of renewed Pliocene uplift. The Green River and Uinta sediments have compacted, giving the Uinta Mountains greater relative relief. Lateral tensions and uneven compaction created long tension fractures which have since filled with gilsonite (uintaite), a petroleum residue (IAPG, 1957; Hunt, 1954).

Regional Stratigraphy

Green River Formation—

The Green River Formation was deposited on the fluvial sandstones of the Wasatch and Mesa Verde Formations. The characteristic feature of the Green River Formation is its lacustrine nature. The Green River Formation is divided into the Douglas Creek, Garden Gulch, and Parachute Creek Members.

Douglas Creek Member—The Douglas Creek Member dates from the Early to Middle Eocene. At Hell's Hole Canyon near the eastern boundary of the tract, it is about 265 meters (870 feet) thick, but is as much as 610 meters (2,000 feet) thick near the axis of the basin. It is composed of interbedded shale, fine- to medium-grained quartz sandstone, siltstone, and limestone. Most of the limestone is oolitic and algal, and some is ostracodal, occurring in thin to massive beds. The member contains little oil shale. Bedding is even, continuous, and uniform.

The Douglas Creek Member intertongues extensively with the underlying Wasatch Formation. It is sometimes difficult to distinguish the fluvial Wasatch tongues from the lacustrine Douglas Creek Member. Part of this difficulty stems from the fact that the Douglas Creek Member was laid down in a shallow, near-shore zone of the freshwater lake.

Garden Gulch Member—The Garden Gulch Member of the Green River Formation is about 90 meters (300 feet) thick in the vicinity of the tracts. It is composed of fine-grained sediments; magnesian marlstone, oil shale, and siltstone. The beds are thin and even. This member contains less oil shale than the Parachute Creek Member above it. It was deposited in shallow water, probably less than 23 meters (75 feet) deep.

Parachute Creek Member—The Parachute Creek Member is approximately 230 meters (750 feet) thick beneath the Federal oil shale lease tracts in Utah. It is formed of marlstone, oil shale, and siltstone. Most beds range from 2.5 cm (1 inch) thick to paper-thin and are laterally very continuous. Distinctive beds less than a centimeter thick can be traced over thousands of square kilometers. This member contains most of the oil shale in the Green River Formation. Much of the rich oil shale in the Parachute Creek Member is contained in the "Mahogany Ledge," a 0.6- to 18-meter (2- to 60-foot) thick zone of rich oil shale. The rich brown color produced by weathering of the oil shale explains the name. The oil shale occurs in beds ranging from several centimeters to paper-thin. Low-grade oil shale weathers to a yellow tan, rich shale to a deep brown, and the richest may remain black, with a white deposit on the surface.

The Parachute Creek Member was evidently deposited in fairly deep water, at it does not show signs of wave disturbance. A chemically reducing environment due to thermal stratification contributed to the preservation of organic matter. Some shallow water sediments are mixed with the deep water layers, indicating fluctuating lake levels.

The thick sequences of oil shale are a feature of the lake's longevity.

The lake was fairly saline during this period. Lake biota was dominated by algae and insect larvae. The remains of these organisms, along with windblown pollen and other plant material from the shore, drifted down through the still, oxygen-deficient depths of the lake. The rate of inorganic sedimentation was very low. Thick beds of highly organic mud were deposited which, under the compaction of further burial, were transformed into kerogen. Very fine grains of quartz and calcite are imbedded in the kerogen matrix.

The sequence at the top of the Green River Formation was named the Evacuation Creek Member by Bradley (1931). Recently Cashion (1974) has demonstrated that the Evacuation Creek Member at its type locality near the White River a short distance above Evacuation Creek is, in fact, identical to the Parachute Creek Member at its type locality in the Piceance Basin. The name "Evacuation Creek Member" has, therefore, been abandoned and the name Parachute Creek Member given to the entire section below the Uinta Formation.

The sequence formerly called the Evacuation Creek Member was originally distinguished from the Parachute Creek Member by a decrease in the number of oil shale beds. The predominant rocks are siltstone and marlstone. A particularly interesting stratum consists of large crystals of nahcolite ($NaHCO_3$) imbedded in a siltstone-marlstone matrix. In many places the nahcolite has been dissolved by water and only cavities remain. Because of the resemblance these cavities bear to mud swallow's nests, Cashion (1967) named the beds the "Bird's Nest Zone." Directly above the Bird's Nest Zone is a fairly thick (1 to 10 meters) bed of sandstone. This sandstone is erosion-resistant and stands out prominently on canyon walls, thus forming a convenient marker bed. Although this has been called "Horse Bench Sandstone," it is probably stratigraphically higher than Cashion's Horse Bench Sandstone. The top of the Parachute Creek Member is dated to the mid-Late Eocene.

Uinta Formation—

The Uinta Formation is composed of massive tuffaceous sandstone alternating with claystone. It is divided into "a" and "b" units by a distinctive bed of tuffaceous sandstone 0.6 to 1.8 meters (2 to 6 feet) thick at the base of the "b," or upper, unit. The top portion of the "b" unit is formed of massive sandstone river channels running from east to west (Dane, 1954). The formation was laid down in floodplain and deltaic environments. In many places the contact with the Green River Formation has been distorted by plastic flow of the fine-grained Green River sediments beneath the load of the denser Uinta sandstones.

Stratigraphy and Structure of Utah Tracts

Nearly all the rock exposed at the surface of the tracts belongs to the Uinta Formation, unit "a." A small part of the Uinta Formation, unit "b," has escaped erosion on the highest ridges (see Figure 5-8). Stratigraphic sections of the Uinta Formation are presented in Figure 5-9. The Green River Formation crops out only along Evacuation Creek. Here the Bird's Nest Zone is traversed by the creek.

The entire sequence of the Green River Formation is found beneath the surface of the tracts. The Douglas Creek Member lies 281 to 533 meters (1,250 to 1,750 feet) below the surface and is about 200 meters (650 feet) thick. The Garden Gulch Member lies between 244 and 366 meters (800 and 1,200 feet) deep, but is only about 70 meters (230 feet) thick. The average thickness of the Parachute Creek Member below the tracts is 222 meters (725 feet). The Mahogany Marker is a 15-cm (6-inch) thick bed of analcitized tuff 3 to 5 meters (10 to 16 feet) above the Mahogany Bed, the thickest bed in the Mahogany Ledge (Figure 5-10 and 5-11). The Mahogany Marker is a convenient reference point because the mining on Tracts U-a and U-b is planned to extend from 6.1 meters (20 feet) above the marker to 12.2 meters (40 feet) below it.

The structure of the Mahogany Marker characterizes the structure of the tracts. The rest of the beds of the Green River Formation lie parallel to the Mahogany Marker, with a dip of less than 5 degrees to the north or northwest. This orientation is typical of the regional structure. Figures 5-12 through 5-14 are cross sections of the tract area made from borehole data.

Faults and Dikes

No faults have been mapped on the tracts. The sandstone-claystone fabric of the Uinta Formation is quite resistant to fracturing. Joints are widely spaced. The major joint set is oriented N62W, 80SW.

Although no gilsonite (uintaite) was found on the tracts by the White River Shale Poject (1976b), Cashion (1967) had mapped two small gilsonite dikes in the area. Field investigations during 1977 verified the dikes (Figure 5-8). The southern dike could not be traced to Evacuation Creek, but the northern dike was observed in the wall of Evacuation Creek Canyon near the Highway 40 crossings. At this location, gilsonite could be seen filling the evaporite solution cavities which form the aquifer, indicating that the dike could serve as an effective aquitard. Despite this characteristic, no effect on either water level or quality caused by the dikes has been detected. The southern dike passes between the closely spaced wells G-10 and X5, yet the water levels in these wells differ by only 2 meters (6 feet).

Possibly the dikes are heavily fractured and thus do not prevent the flow of groundwater. However, even if the dikes are impermeable, they would probably not disturb the groundwater flow significantly because they are nearly parallel to the direction of flow. Recharge or other water flowing from the direction of Evacuation Creek would simply divide and flow parallel to the dikes without alteration in direction.

The fractures were not created by movement of gilsonite. The gilstonite moved into preexisting fractures. The existence of dikes on the tracts indicates the possibility of the presence of unfilled fractures. Such fractures would act as connections between the Douglas Creek and deeper aquifers, and the Bird's Nest Aquifer.

GROUNDWATER HYDROLOGY

Three aquifers contain nearly all of the water found beneath the tracts. The main aquifer is the Bird's Nest Zone in the Parachute Creek Member. The

Douglas Creek Member also contains significant amounts of groundwater. A small, isolated aquifer was found below well P-2. The deep Wasatch and Mesa Verde Formations may contain significant aquifers, but no water wells have been drilled below the Green River Formation.

Bird's Nest Aquifer

Near Evacuation Creek, and in general beneath the tracts, the Bird's Nest Aquifer is formed by approximately six zones 1 meter (3 feet) thick pocked with numerous nahcolite solution cavities. These solution cavities have an irregular, elliptical shape 1 to 30 cm (0.5 to 15 inches) long. The spacing of the zones varies from 1 to 5 meters (3 to 20 feet). Occasional solution cavities occur between the zones. About 18 meters (60 feet) above the topmost zone is a 2-meter (6-foot) bed of yellow, fine-grained, moderately sorted, compact, massive sandstone. According to well logs, the water contained in this sandstone has a higher electrical resistivity than that in the solution cavity zone. The aquifer is in contact with the alluvium of Evacuation Creek for the entire distance between the site of Watson (surface water gaging station S-6) and Station S-2 at the Highway 40 bridge (Figure 5-16). The White River traverses the aquifer a short distance below its confluence with Evacuation Creek.

Characterization of the nature and extent of the aquifer is crucial in determining recharge-discharge relationships. Figure 5-16 is a map of the outcrop of the Bird's Nest Zone and related water-bearing zones. Near the oil shale lease tracts nahcolite solution cavities are numerous and form the most important water-bearing zone. The solution cavity aquifer is still well developed in the Asphalt Wash area to the southwest of the tracts. Although no solution cavity zone was observed at Bitter Creek in the measured section or above or below it, Cashion (1967) does record them in his stratigraphic section of the area. This inconsistency would be natural if the solution cavity zone were feathering out in the area.

West of Bitter Creek the sandstone zone predominates. Although solution cavities are still present, they are scattered and assume much less importance as groundwater conductors. The sandstone zone, on the other hand, is thicker and interbeds with thin marlstone layers. In summary, the aquifer beneath the tracts is predominantly a solution cavity aquifer with some sandstone, while it is mainly a sandstone aquifer with some solution near the Green River.

One interesting feature of the stratigraphic sections is the association of oil shale and nahcolite nodules. Although only in one location (the Evacuation Creek section) does a nahcolite zone actually lie in an oil shale bed, they generally occur in close proximity. Outcrops without these zones do not possess oil shale. This suggests that the thermal stratification which produced reducing conditions important for formation of oil shale was accompanied by saline density stratification. Such a phenomenon has been observed in East African lakes. The greater density of the saline water helps to permanently prevent annual overturn. If such is the case, the development of the nahcolite nodules, and thus a solution cavity zone, should coincide with oil shale thickness. Figure 1-1 shows extensive oil shale development all the way from the lease tracts to the vicinity of Willow Creek, suggesting a direct hydrologic connection between these points.

A continuous, well-developed, water-bearing zone connects the Asphalt Wash areas and the tracts, and probaby the area north of Willow Creek and the tracts. The connection of the creek west of Asphalt Wash with the well-developed solution cavity aquifer is through less continuous and less permeable sandstone. The same situation exists where the aquifer zone is traversed by the Green River.

Just east of the tracts, the Uinta Basin begins to curve to the north and finally to the west. Because of the asymmetric nature of the basin the strata along the northern edge of the basin dip steeply to the south. The Bird's Nest Aquifer may lie beneath the Duchesne Formation in this area. The structure of the aquifer conforms to the general basin shape (Figure 5-17).

Although the zone is everywhere confined by impermeable layers except where erosion has removed them close to outcrops, in many places the complete thickness is not saturated and thus the aquifer is under water table conditions. From Figure 5-18 it can be seen that water table conditions prevail close to Evacuation Creek and around the southern boundary of the tracts. North of the boundary the entire thickness of the zone is saturated and forms a confined aquifer.

The hydraulic characteristics of the Bird's Nest Aquifer are by no means homogeneous. The transmissivity of the aquifer under Tract U-b is only about 5 percent of that under Tract U-a. Transmissivities calculated by various methods are summarized in Table 5-2. The transmissivity at well P-1 is about 0.2 liters per second per meter or 17,280 liters per day per meter (1,500 gallons per day per foot). The test pumping rate was limited to 2.8 liters/second (45 gallons/minute) due to the necessity of disposing of the pumped water in a holding pond. Well P-3, also in Tract U-b, was found to have a transmissivity of only 0.002 liters per second per meter (15 gallons per day per foot). Pumping at the rate of 0.2 liters/second (3.17 gal/min) dewatered the aquifer in this location in 30 minutes. The aquifer is under water table conditions and the saturated thickness at this point is much less than at well P-1.

In contrast, the aquifer at well P-2, in Tract U-a, was determined to have a transmissivity of 10.8 liters per second per meter (75,000 gallons per day per foot). Six days of pumping at 35 liters/second (550 gal/min) produced only 5.5 meters (18 feet) of drawdown. Groundwater evaluations conducted for this monitoring design study indicated steep gradients under Tract U-b and more flat gradients under Tract U-a (Figure 5-19). The probable explanation is the great increase in transmissivity beneath U-a. The water-level map developed by the White River Shale Project is included for comparison (Figure 5-20). The assumptions used in constructing Figure 5-19 are:

1. Well P-4 was not included as it clearly taps the Douglas Creek Aquifer.

2. Well G-17 was excluded since it stops short of the Bird's Nest Aquifer.

3. Well X-5 was excluded because the water level, 130 feet above Evacuation Creek at a distance of 800 feet from the Creek, seemed unrealistic. This well was a geologic borehole and was never pumped. It may be receiving leakage from above the Bird's Nest Aquifer, rainwater, or contain drill fluid.

4. Recharge was assumed from upper Evacuation Creek and discharge from lower Evacuation Creek.

5. Discharge was assumed into White River below Evacuation Creek and no other connection. Figure 5-18 has been redrawn on the basis of these assessments and is shown in Figure 5-21.

The Bird's Nest Aquifer must be recharged by Evacuation Creek, since it is in contact with the saturated alluvium of the creek and the aquifer gradient would lead to westward flow. However, if such recharge is occurring, the flow of Evacuation Creek should be diminished between stream gages S-6 and S-2, but it is not. Recharge from Evacuation Creek also does not satisfactorily explain the water quality distribution of the Bird's Nest Aquifer (see Section 6). Discharge from the aquifer to Evacuation Creek can be observed below the Highway 45 bridge, and to White River below its confluence with Evacuation Creek. The observed discharge is small. These are the only observed discharge points of the aquifer.

Probably some recharge of the aquifer from Asphalt Wash occurs. The curvature of the 1,480-meter (4,850-foot) equipotential line in Figure 5-20 supports this observation. Recharge very likely also takes place where the alluvial channels of the perennial streams to the west of the tracts traverse the aquifer. Water passing beneath the tracts could not discharge to any of the streams to the west since they all traverse the aquifer at a higher elevation than the White River traverses it just north of the tracts. The Green River, however, traverses the aquifer at a lower elevation than the White River, and thus may be a discharge point for water passing beneath the tracts. Thomas (1952) estimates that groundwater inflow to the river between Ouray and Green River, Utah, amounts to 56.6 liters/second (120 ft^3/min). Since the river traverses several other water-bearing formations in this distance, only a part of the inflow could be from the Bird's Nest Aquifer. Considering the discontinuous and heterogeneous nature of the aquifer between the tracts and the Green River, and the distance of about 48 km (30 miles), it is likely that the rate of discharge is slow. The aquifer may also discharge by upward leakage to higher formations. Such leakage has been noted in a similar aquifer in the Piceance Basin in Colorado.

Douglas Creek Aquifer

The Douglas Creek Member lies about 500 feet below the Mahogany Zone in the vicinity of the tracts. Two wells were drilled into this member during environmental baseline studies on the tracts. Well G-16A flowed at the surface after the Douglas Creek Member was tapped. Two oil and gas exploration wells in Asphalt Wash have been converted to stock-watering wells. These wells draw from the Douglas Creek Aquifer and also flow at the surface. Thus the Douglas Creek Aquifer seems to be at a higher head than any of the aquifers above it. No aquifer tests were performed on it, so its hydraulic properties are unknown. It may, however, have the highest production rate of any water-bearing zone in the Green River Formation.

P-2 Upper Aquifer

A small aquifer was discovered above the Bird's Nest Aquifer at well P-2. The aquifer is of limited areal extent and low transmissivity (0.02 liters per second per meter [150 gallons per day per foot]). Calculations of the storage coefficient varied from 1.0×10^{-5} to 1.5×10^{-5}. The water level in P-2 lower (Bird's Nest Aquifer) is below the base of the P-2 upper aquifer, indicating the possibility that P-2 upper is a perching layer. Pumping in either of the aquifers did not affect the other. Several months after an aquifer pump test at the P-2 upper aquifer, the water levels had not fully recovered.

Alluvial Aquifers

Little information is available on the hydrologic characteristics of the alluvial materials in ephemeral stream valleys on the tracts. Some water quality data have been collected and are presented in Section 6.

SURFACE WATER HYDROLOGY

The largest surface flow through the tracts is that of the White River. The mean annual flow is 19.9 m^3/s (cubic meters per second) (702 ft^3/s). A 20-year hydrograph is presented in Figure 5-22. The source of the yearly maximum flow is snowmelt. The August-April flow is supplied by groundwater base flow (Figure 5-23). Since the source of the White River is the high mountains to the east, its flow is more dependable than that of streams originating in the arid Uinta Basin.

The water quality of White River is better than that of the other streams in the area. The mean total dissolved solids concentration is about 500 mg/l. As expected, the dissolved solids concentration decreases with increased flow. The water quality is typical of the region in that the major dissolved constituents are calcium, sodium, bicarbonates, and sulfates. The fact that these constituents decrease dramatically during high flow periods while the other constituents decrease proportionately less indicates that they are probably contributed by the groundwater base flow (Figures 5-24 and 5-25). Data collected during baseline studies of the project area (WRSP, 1976b) commonly showed increases in major groundwater quality constituents, sodium and sulfate, between Hell's Hole Canyon and Southam Canyon. Part of this increase is probably due to inflow from Evacuation Creek, but some may be due to seepage from the Bird's Nest Aquifer.

Evacuation Creek is a small tributary of the White River. The mean daily flow (at gaging station S-2) has varied from zero to 2.0 m^3/s (71 ft^3/s). The drainage area of the creek is 770 km^2 (280 mi^2). Peak flows in the creek depend much more on local rainfall than do peak flows of the White River. The hydrograph (Figures 5-26 and 5-27) is typical of small streams in arid regions, and is characterized by long periods of very low flow broken by short, steep flood peaks. In many locations the surface of the streambed is regularly dry with water movement continuing in the alluvial aquifer. The streamflow near the confluence with the White River is equal to or slightly less than the flow upstream near the site of Watson.

The quality of Evacuation Creek water is much poorer than that of White River water (Figures 5-28 and 5-29). Total dissolved solids average about 3,800 mg/l. The predominant constituents are sodium and sulfate. One of the interesting features of this creek system is that the concentrations of some of the major constituents are less at the downstream station than they are upstream, near Watson (Figure 5-28). Under low flow conditions, average dissolved solids content near Watson is 4,950 mg/l while near the confluence with the White River it averages 3,830 mg/l. Figure 5-28 shows that the decrease is largely accounted for by lower sodium sulfate concentration. Figure 5-29, a comparison of high water period composition, shows what would more normally be expected, a slight increase in dissolved solids downstream due to additions by dissolution and concentration by evaporation. The fact that this phenomenon is observed only during base flow periods suggests that it is groundwater related. Simple dilution cannot account for the change because no tributaries enter the stream and the streamflow does not increase between the two stations.

Two possible explanations exist. Precipitation of sodium sulfate may occur along the stream source. However, the high solubility of sodium sulfate does not support this explanation. Ion exchange might change the ionic balance, but would not decrease the total equivalent concentration. The other possible explanation is groundwater exchange. The creek alluvium is in contact with the Bird's Nest Zone for the entire distance between the stations. Exchange of high TDS creek water for lower TDS aquifer water could lower the dissolved solids content of the creek water without increasing the flow. This problem is discussed in more detail in Section 6.

Other watercourses on the tracts flow only after local rainfall events. The largest of these ephemeral stream drainages is Southam Canyon. Water typically flows out of this canyon only once or twice a year. Table 5-3 is a water balance for the 1975 water year in Southam Canyon. Note that this tabulation assumes, probably incorrectly, no groundwater outflow.

Table 5-4 presents peak streamflow statistics for Hell's Hole and Southam Canyons and Asphalt Wash. The results vary widely depending on the method used. All of the methods are designed to work with general area precipitation and basin characteristics rather than historic flow data.

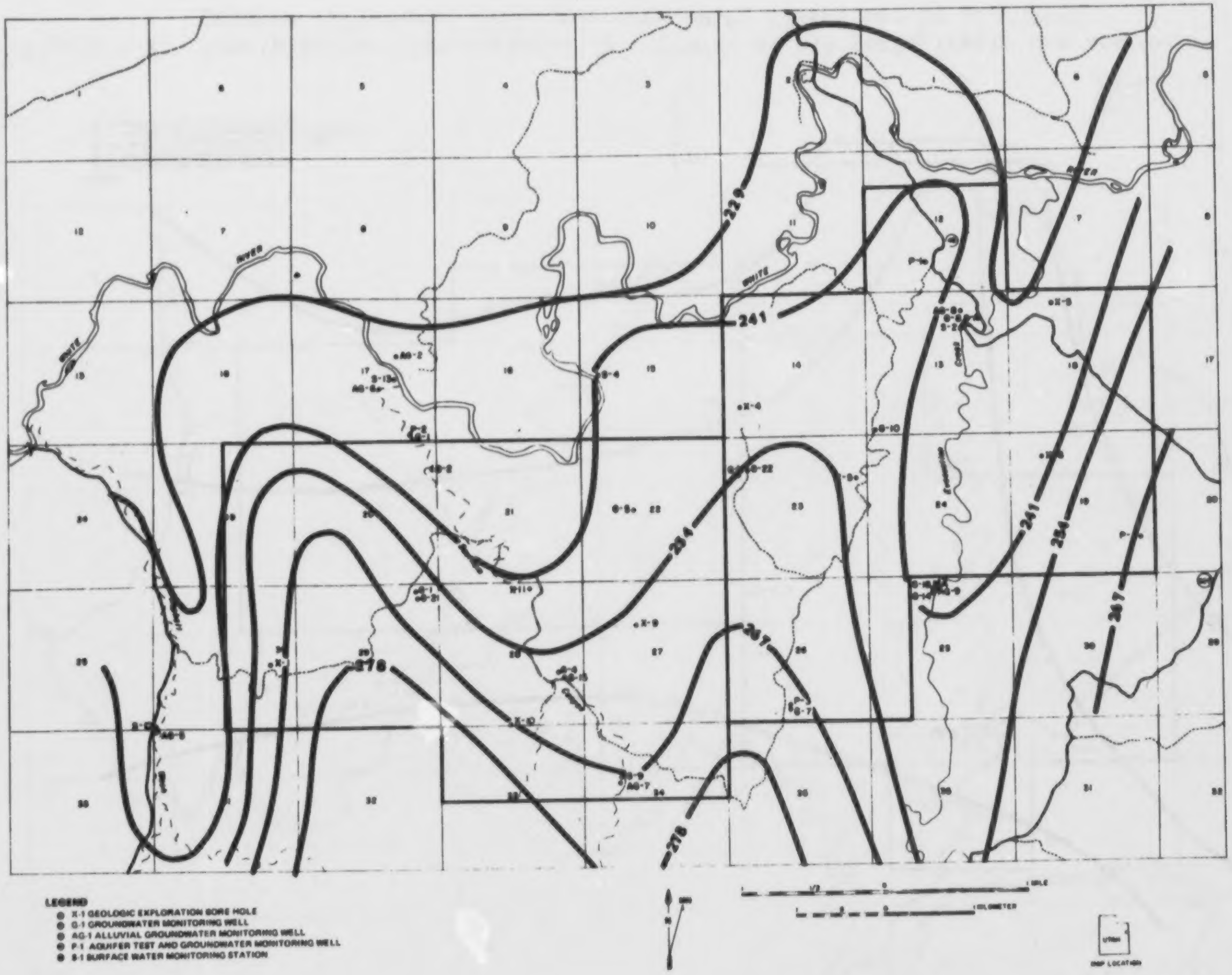
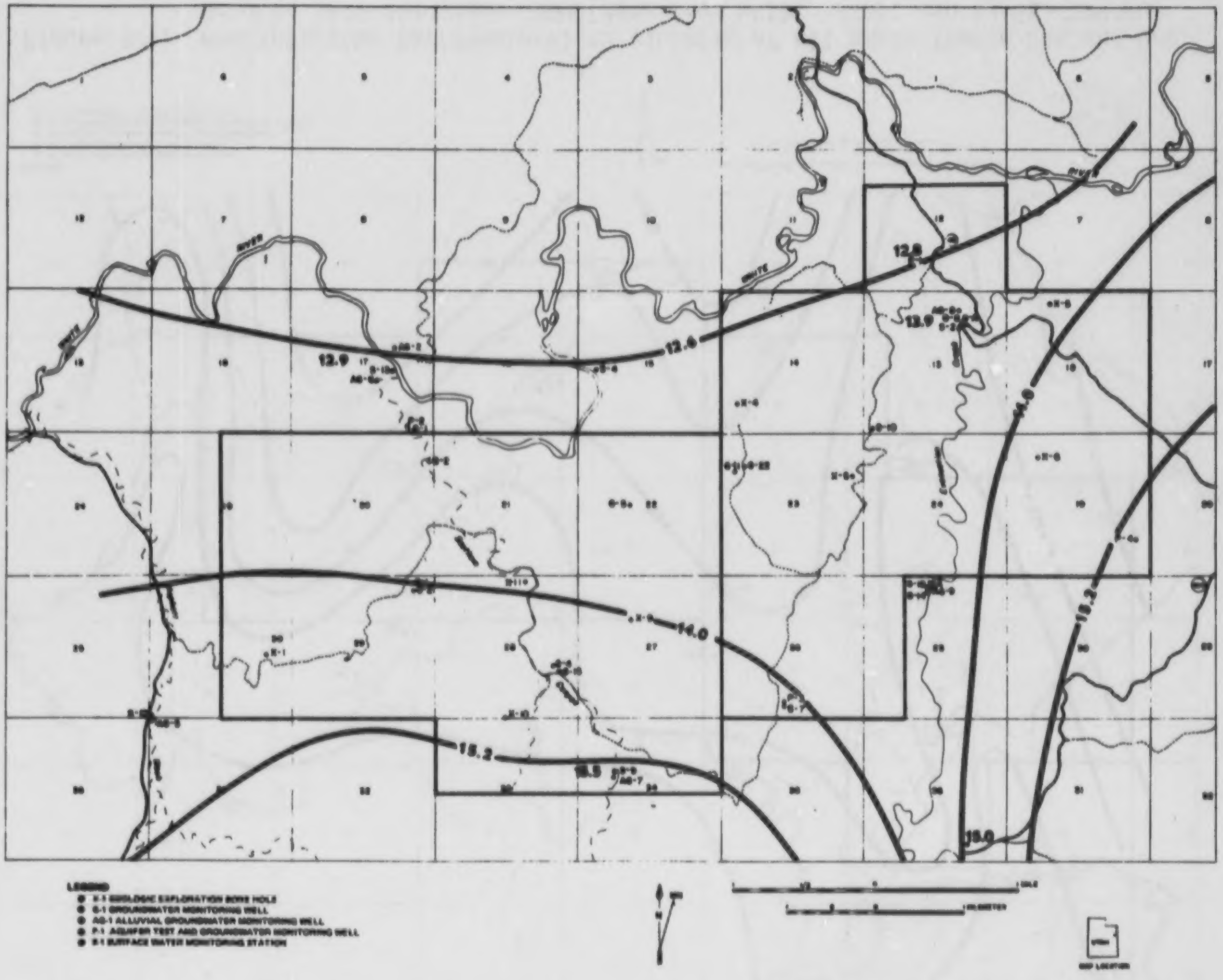

229
241
254
267
278
WHITE RIVER
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
1 MILE
KILOMETER
UTAH
MAP LOCATION

Figure 5-1. Precipitation (millimeters) in vicinity of oil shale Tracts U-a and U-b, October 1974—September 1975 (data from WRSP, 1976b; map by GE—TEMPO).



12.9
12.6
12.8
12.9
14.0
15.2
15.5
15.0
WHITE RIVER
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
UTAH
MAP LOCATION

Figure 5-2. Precipitation (centimeters) in vicinity of oil shale Tracts U-a and U-b, October 1974–April 1975 (data from WRSP, 1976b; map by GE–TEMPO).

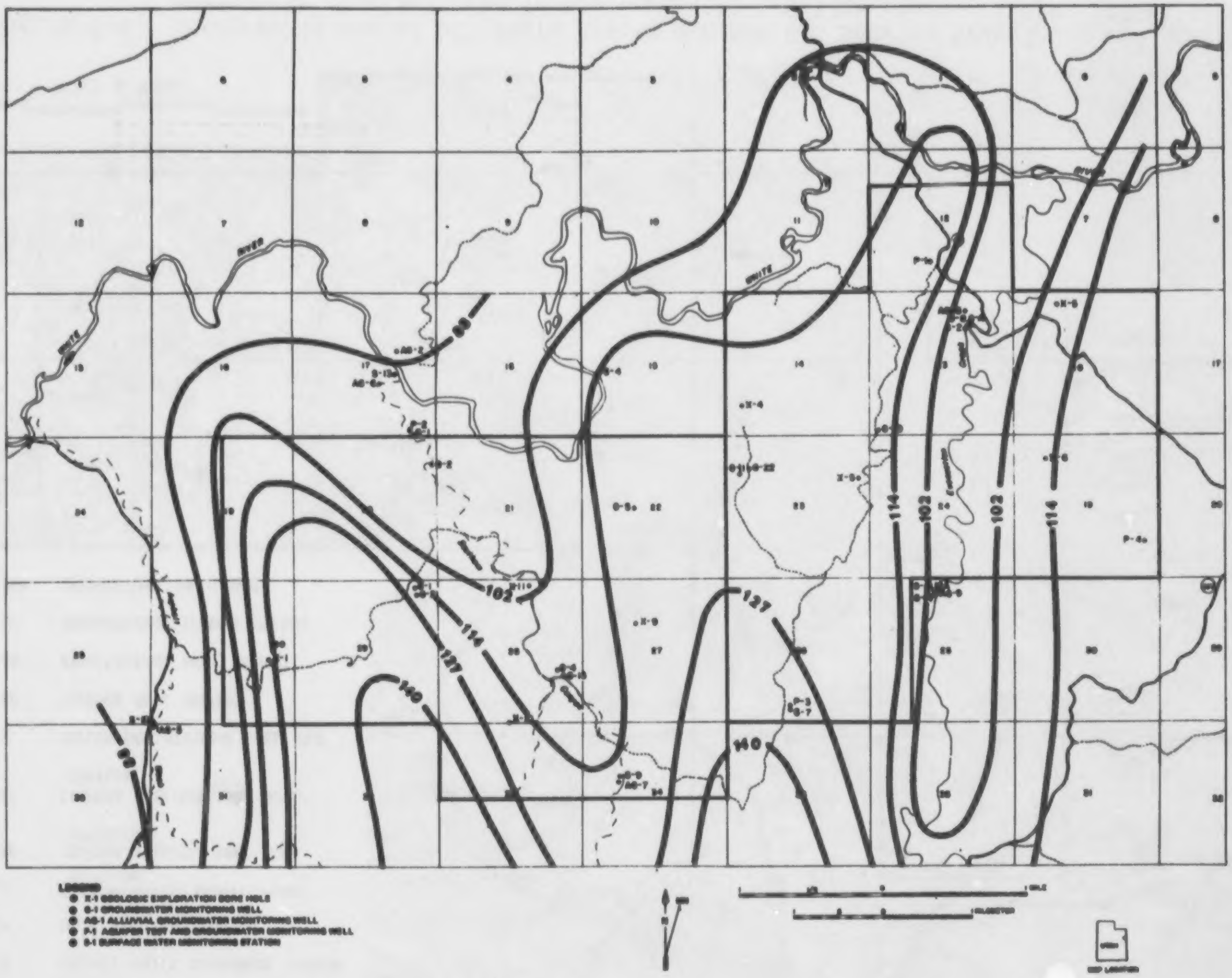

114
102
102
114
89
89
102
114
127
140
127
140
White River
LEGEND
X-1 GEOLOGIC EXPLORATION CORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MAP LOCATION

Figure 5-3. Precipitation (millimeters) in vicinity of oil shale Tracts U-a and U-b, May 1975—September 1975 (data from WRSP, 1976b; map by GE—TEMPO).

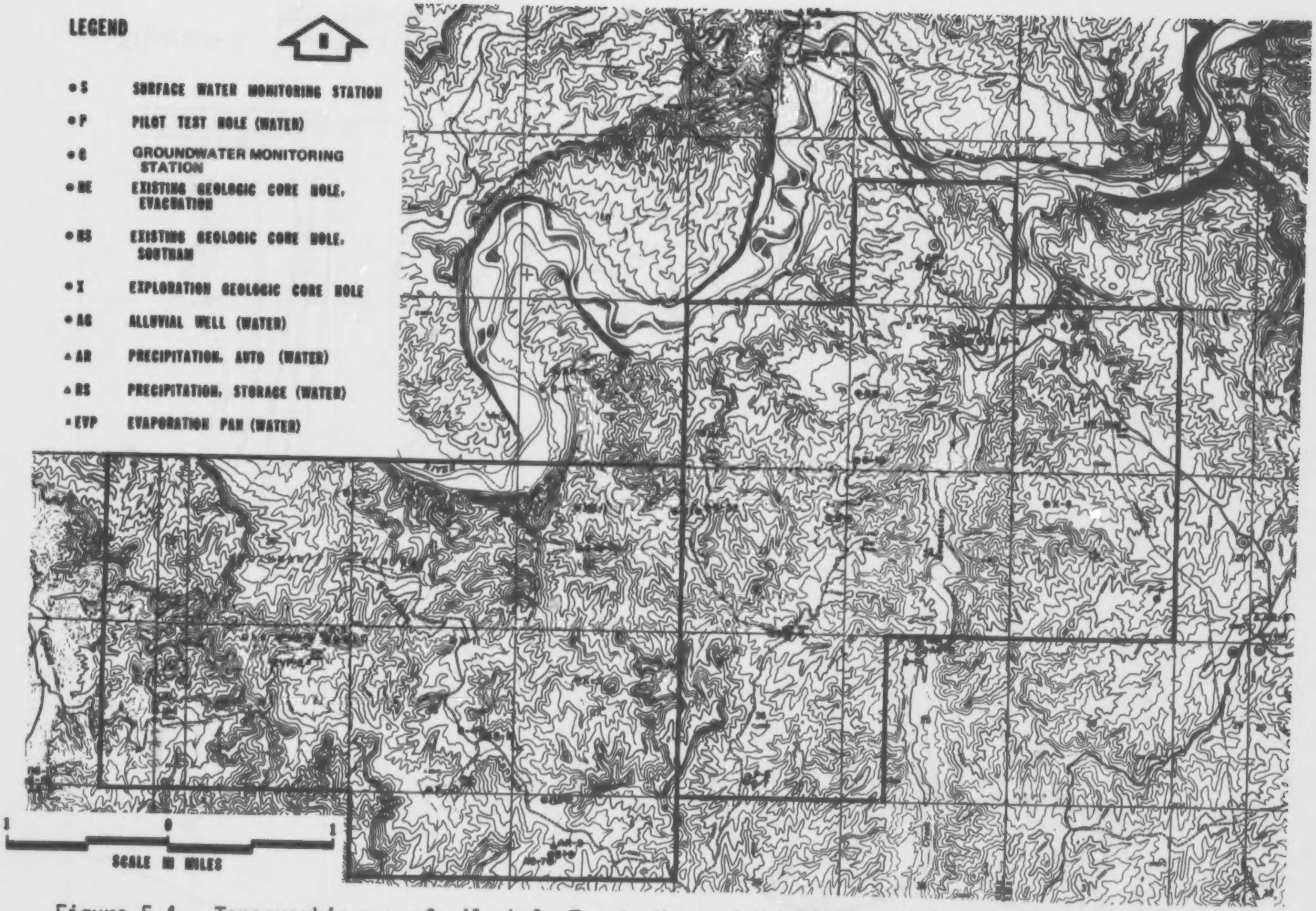
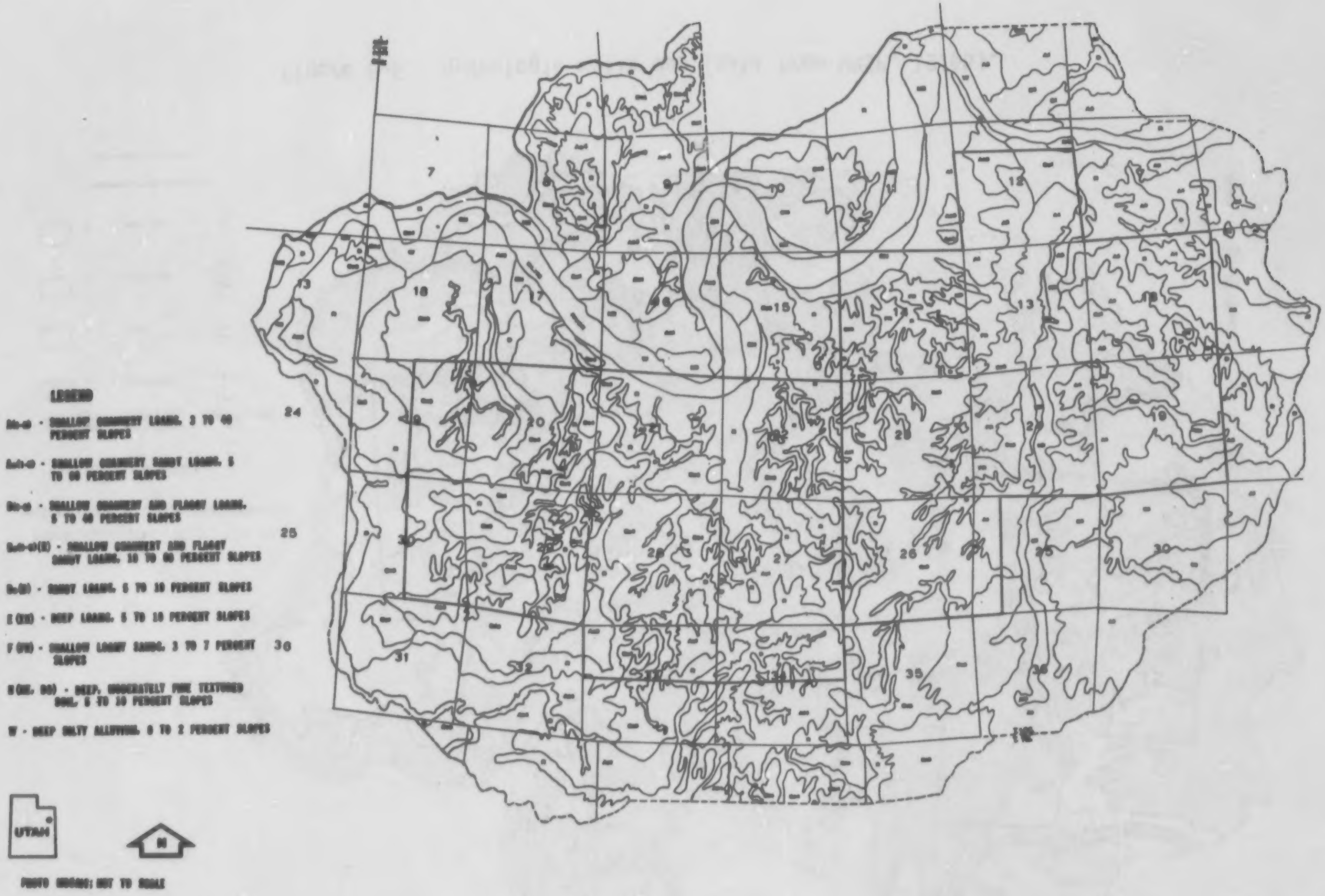

LEGEND
● S SURFACE WATER MONITORING STATION
● P PILOT TEST HOLE (WATER)
● G GROUNDWATER MONITORING STATION
● HE EXISTING GEOLOGIC CORE HOLE, EVACUATION
● HS EXISTING GEOLOGIC CORE HOLE, SOUTHAM
● X EXPLORATION GEOLOGIC CORE HOLE
● AG ALLUVIAL WELL (WATER)
▲ AR PRECIPITATION, AUTO (WATER)
▲ RS PRECIPITATION, STORAGE (WATER)
■ EVP EVAPORATION PAN (WATER)
1
0
1
SCALE IN MILES

Figure 5-4. Topographic map of oil shale Tracts U-a and U-b showing hydrologic and geologic monitoring stations used in environmental baseline studies (WRSP, 1976b).



LEGEND
Bb-e - SHALLOW CHANNERY LOAMS, 3 TO 40 PERCENT SLOPES
Bcb-e - SHALLOW CHANNERY SANDY LOAMS, 5 TO 60 PERCENT SLOPES
Bb-e - SHALLOW CHANNERY AND FLAGGY LOAMS, 5 TO 40 PERCENT SLOPES
Bcb-e(E) - SHALLOW CHANNERY AND FLAGGY SANDY LOAMS, 10 TO 60 PERCENT SLOPES
Bc(E) - SANDY LOAMS, 5 TO 10 PERCENT SLOPES
E (XX) - DEEP LOAMS, 5 TO 10 PERCENT SLOPES
F (FR) - SHALLOW LOAMY SANDS, 3 TO 7 PERCENT SLOPES
H (HL, HO) - DEEP, MODERATELY FINE TEXTURED SOIL, 5 TO 10 PERCENT SLOPES
W - DEEP SILTY ALLUVIUM, 0 TO 2 PERCENT SLOPES
UTAH
N
PHOTO MOSAIC; NOT TO SCALE
24
25
30
7
8
9
10
11
12
13
18
17
16
15
14
13
19
20
21
22
23
24
19
30
29
28
27
26
25
30
31
32
33
34
35
36

Figure 5-5. Soils map of oil shale Tracts U-a and U-b (WRSP, 1976b).

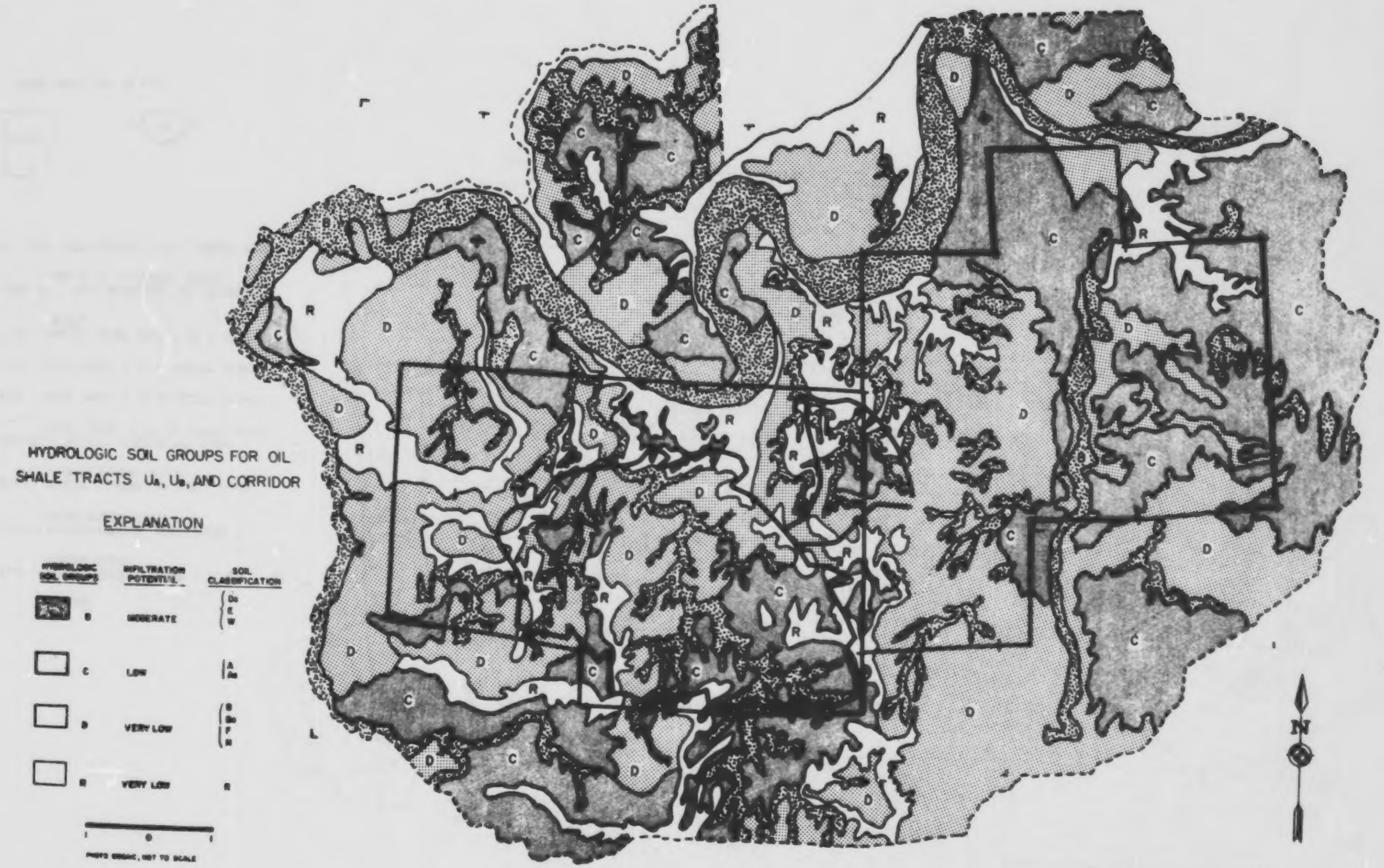

HYDROLOGIC SOIL GROUPS FOR OIL SHALE TRACTS Ua, Ub, AND CORRIDOR
EXPLANATION
HYDROLOGIC SOIL GROUPS
INFILTRATION POTENTIAL
SOIL CLASSIFICATION
B
MODERATE
C
LOW
A
D
VERY LOW
R
VERY LOW
R
1
0
1
PHOTO MOSAIC, NOT TO SCALE
N
C
D
R
T
L

Figure 5-6. Hydrologic soils map (data from WRSP, 1976b).

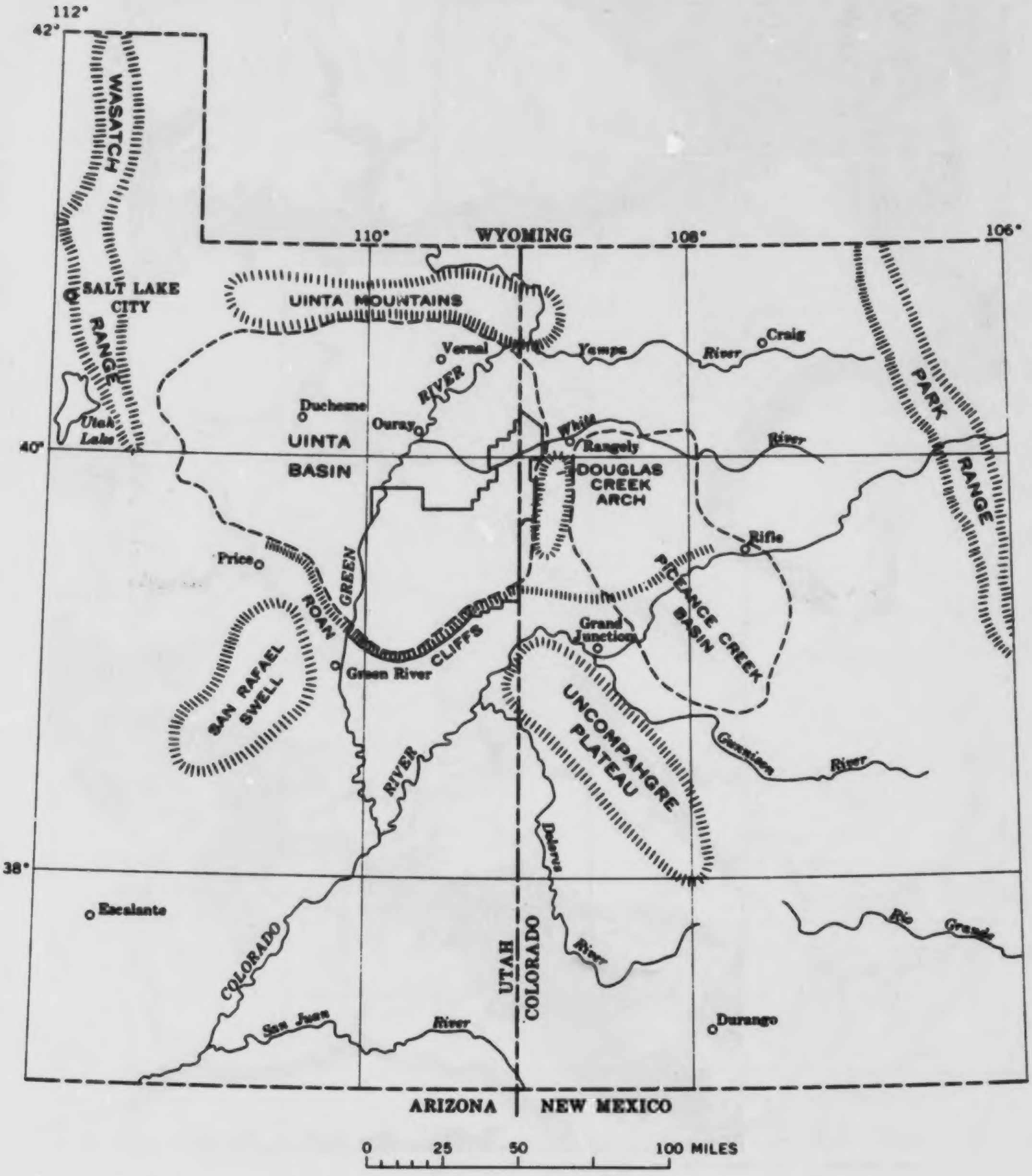

112°
42°
WASATCH
SALT LAKE CITY
RANGE
Utah Lake
110°
WYOMING
108°
106°
UINTA MOUNTAINS
Vernal
Yampa
River
Craig
PARK
RANGE
RIVER
Duchesne
Ouray
UINTA
BASIN
White
Rangely
River
DOUGLAS CREEK ARCH
40°
Rifle
Price
GREEN
ROAN
CLIFFS
PICEANCE CREEK BASIN
Grand Junction
SAN RAFAEL SWELL
Green River
UNCOMPAHGRE PLATEAU
Gunnison
River
RIVER
Dolores
38°
Escalante
Rio Grande
COLORADO
River
UTAH
COLORADO
San Juan
River
Durango
ARIZONA
NEW MEXICO
0
25
50
100 MILES

Figure 5-7. Major structural features in study area (modified from Cashion, 1967).

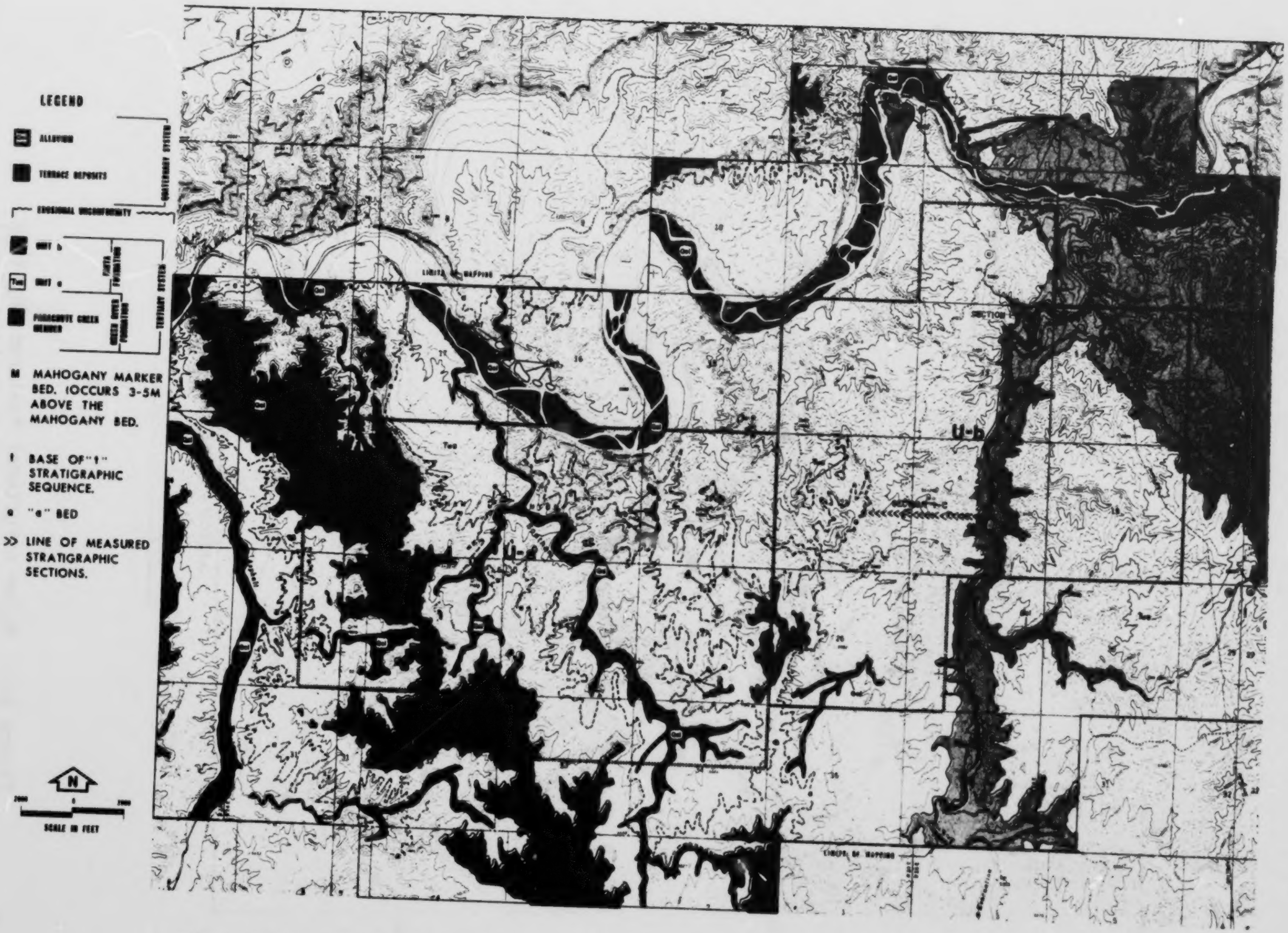

LEGEND
ALLUVIUM
TERRACE DEPOSITS
QUATERNARY SYSTEM
EROSIONAL UNCONFORMITY
UNIT b
Tua
UNIT a
UINTA FORMATION
PARACHUTE CREEK MEMBER
GREEN RIVER FORMATION
TERTIARY SYSTEM
M MAHOGANY MARKER BED. (OCCURS 3-5M ABOVE THE MAHOGANY BED.
t BASE OF "t" STRATIGRAPHIC SEQUENCE.
a "a" BED
>> LINE OF MEASURED STRATIGRAPHIC SECTIONS.
N
2000
0
2000
SCALE IN FEET
U-a
U-b
LIMITS OF MAPPING
SECTION

Figure 5-8. Geologic map of oil shale Tracts U-a and U-b (WRSP, 1976b).

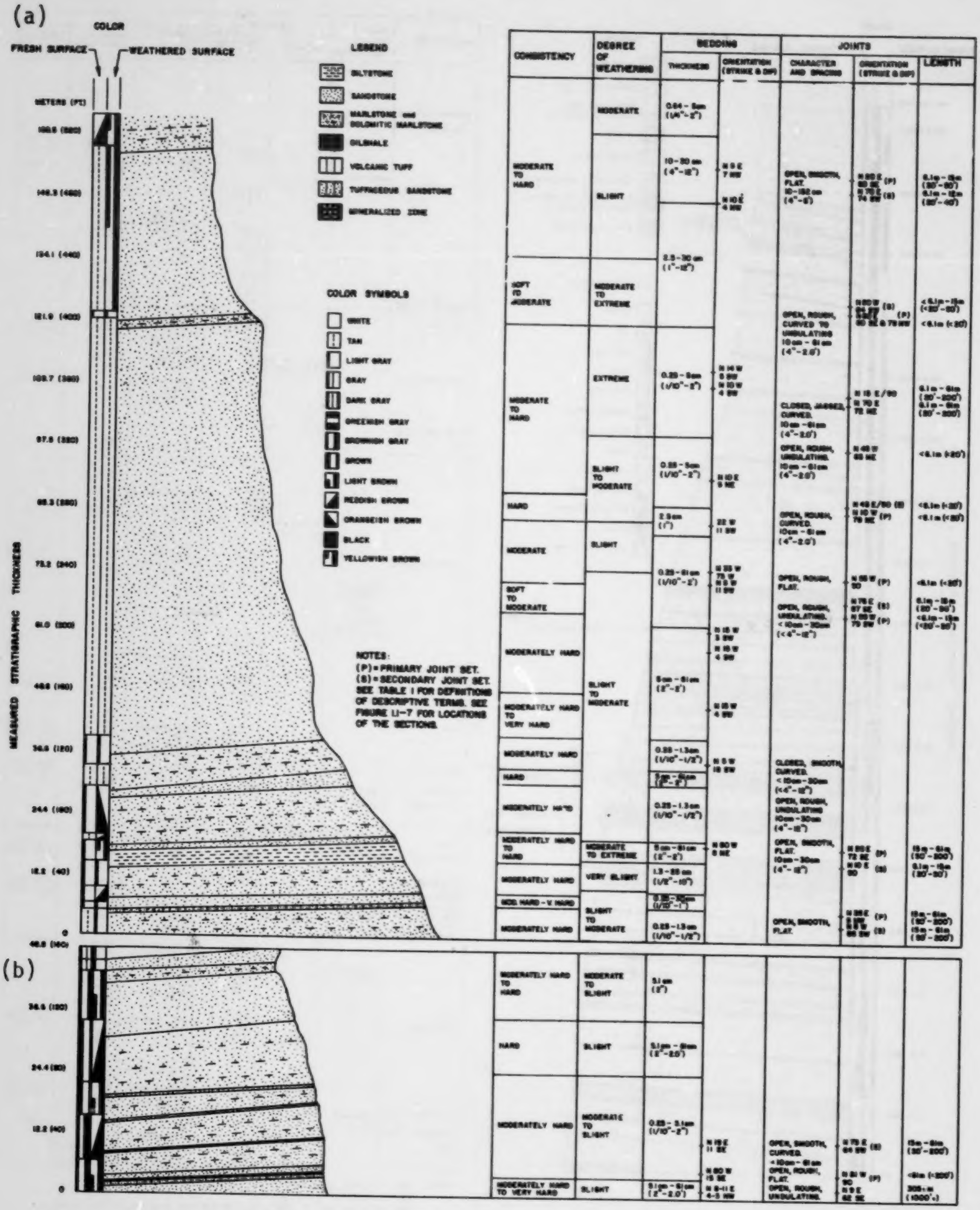
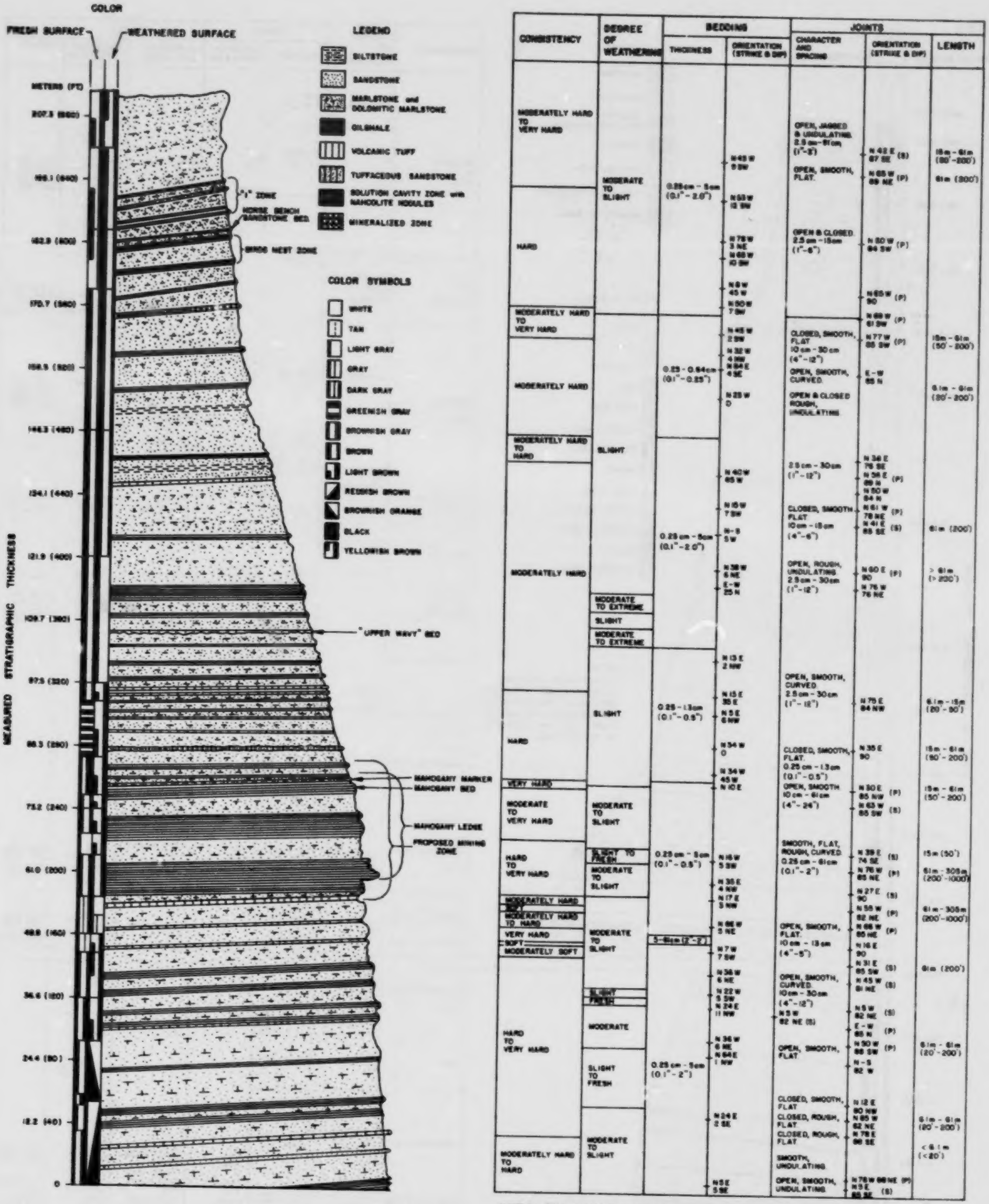

(a)
COLOR
FRESH SURFACE
WEATHERED SURFACE
METERS (FT)
MEASURED STRATIGRAPHIC THICKNESS
LEGEND
SILTSTONE
SANDSTONE
MARLSTONE and DOLOMITIC MARLSTONE
OILSHALE
VOLCANIC TUFF
TUFFACEOUS SANDSTONE
MINERALIZED ZONE
COLOR SYMBOLS
WHITE
TAN
LIGHT GRAY
GRAY
DARK GRAY
GREENISH GRAY
BROWNISH GRAY
BROWN
LIGHT BROWN
REDDISH BROWN
ORANGEISH BROWN
BLACK
YELLOWISH BROWN
NOTES:
(P)=PRIMARY JOINT SET.
(S)=SECONDARY JOINT SET.
SEE TABLE I FOR DEFINITIONS OF DESCRIPTIVE TERMS. SEE FIGURE II-7 FOR LOCATIONS OF THE SECTIONS.
CONSISTENCY
DEGREE OF WEATHERING
BEDDING
THICKNESS
ORIENTATION (STRIKE & DIP)
JOINTS
CHARACTER AND SPACING
ORIENTATION (STRIKE & DIP)
LENGTH
(b)

Figure 5-9. Stratigraphic sections of (a) Uinta Formation (Section 1-C in Figure 5-8) and (b) contact between Uinta and Green River Formations (Section 1-B in Figure 5-8) (WRSP, 1976b).


COLOR
FRESH SURFACE
WEATHERED SURFACE
METERS (FT)
207.3 (680)
195.1 (640)
182.9 (600)
170.7 (560)
158.5 (520)
146.3 (480)
134.1 (440)
121.9 (400)
109.7 (360)
97.5 (320)
85.3 (280)
73.2 (240)
61.0 (200)
48.8 (160)
36.6 (120)
24.4 (80)
12.2 (40)
0
MEASURED STRATIGRAPHIC THICKNESS
"J" ZONE
HORSE BENCH SANDSTONE BED
BIRDS NEST ZONE
"UPPER WAVY" BED
MAHOGANY MARKER
MAHOGANY BED
MAHOGANY LEDGE
PROPOSED MINING ZONE
LEGEND
SILTSTONE
SANDSTONE
MARLSTONE and DOLOMITIC MARLSTONE
OILSHALE
VOLCANIC TUFF
TUFFACEOUS SANDSTONE
SOLUTION CAVITY ZONE with NAHCOLITE NODULES
MINERALIZED ZONE
COLOR SYMBOLS
WHITE
TAN
LIGHT GRAY
GRAY
DARK GRAY
GREENISH GRAY
BROWNISH GRAY
BROWN
LIGHT BROWN
REDDISH BROWN
BROWNISH ORANGE
BLACK
YELLOWISH BROWN
CONSISTENCY
DEGREE OF WEATHERING
BEDDING
THICKNESS
ORIENTATION (STRIKE & DIP)
JOINTS
CHARACTER AND SPACING
ORIENTATION (STRIKE & DIP)
LENGTH

NOTES: (P) = PRIMARY JOINT SET
(S) = SECONDARY JOINT SET
SEE GEOLOGIC MAP OF TRACTS Ua - Ub FOR THE LOCATION OF THE SECTION
SEE TABLE I FOR DEFINITIONS OF THE TERMS USED TO DESCRIBE THE PHYSICAL CHARACTERISTICS OF BEDROCK

Figure 5-10. Stratigraphic section of upper portion of Parachute Creek Member (Section 1-A in Figure 5-8) (WRSP, 1976b).

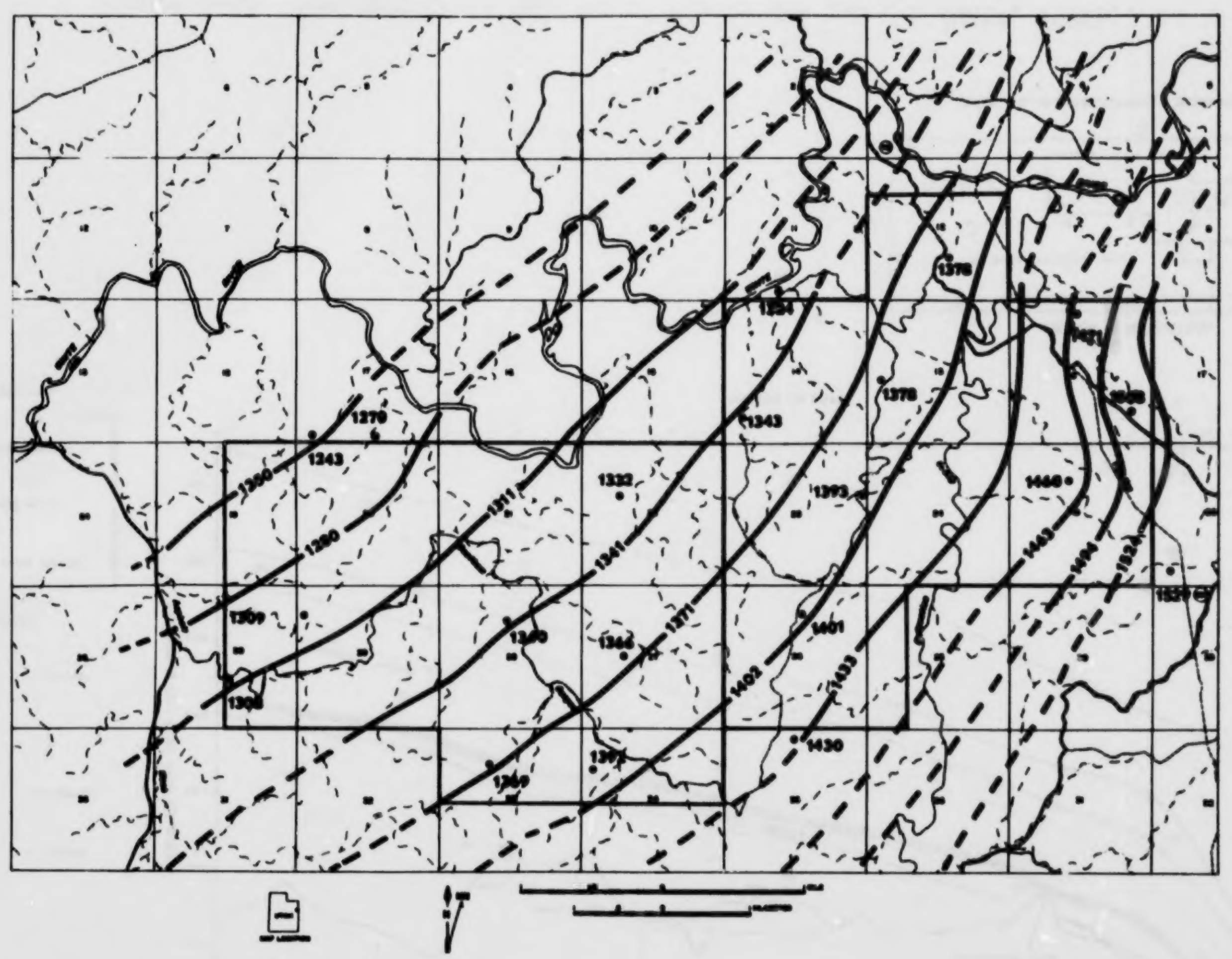
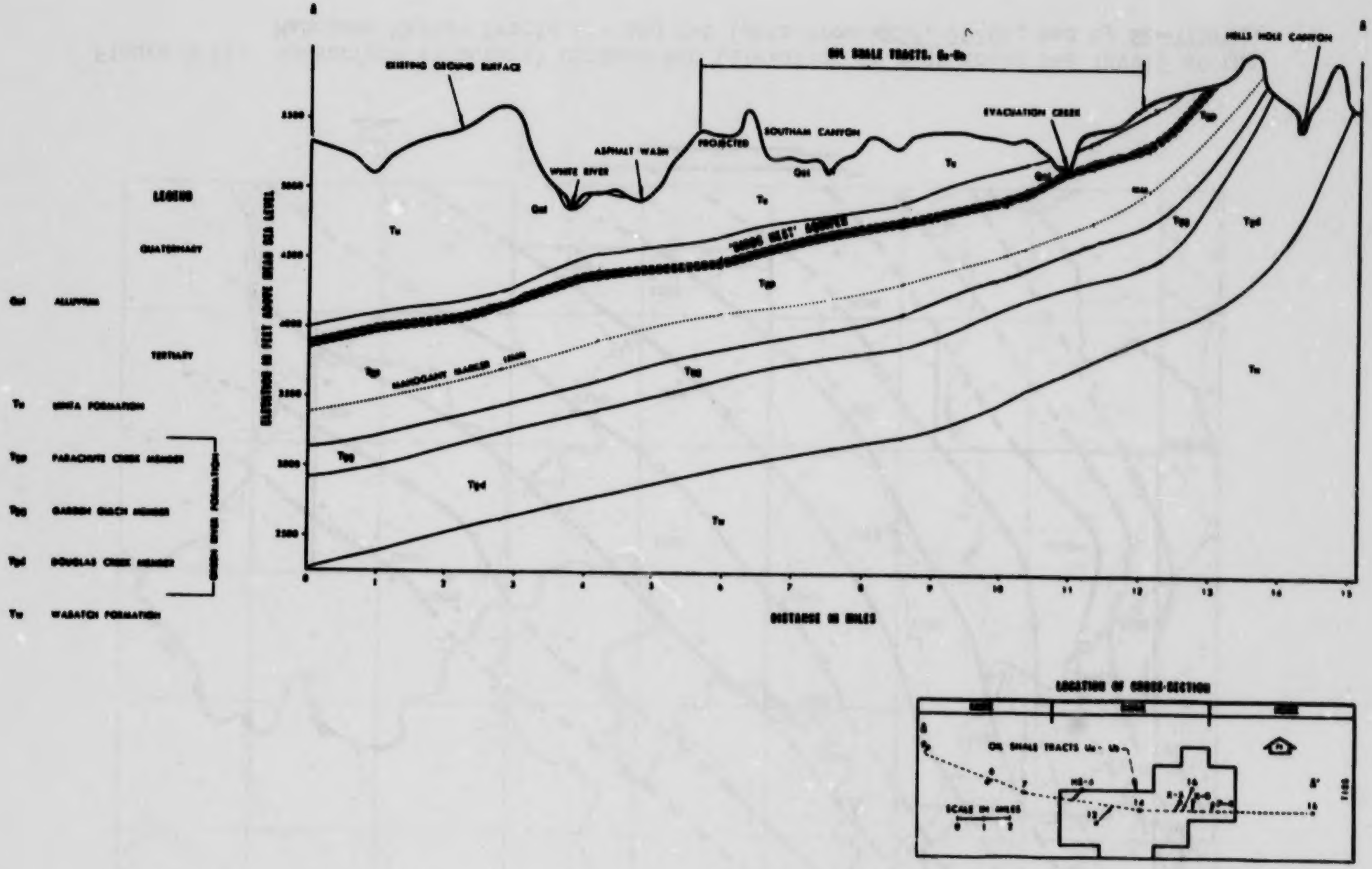
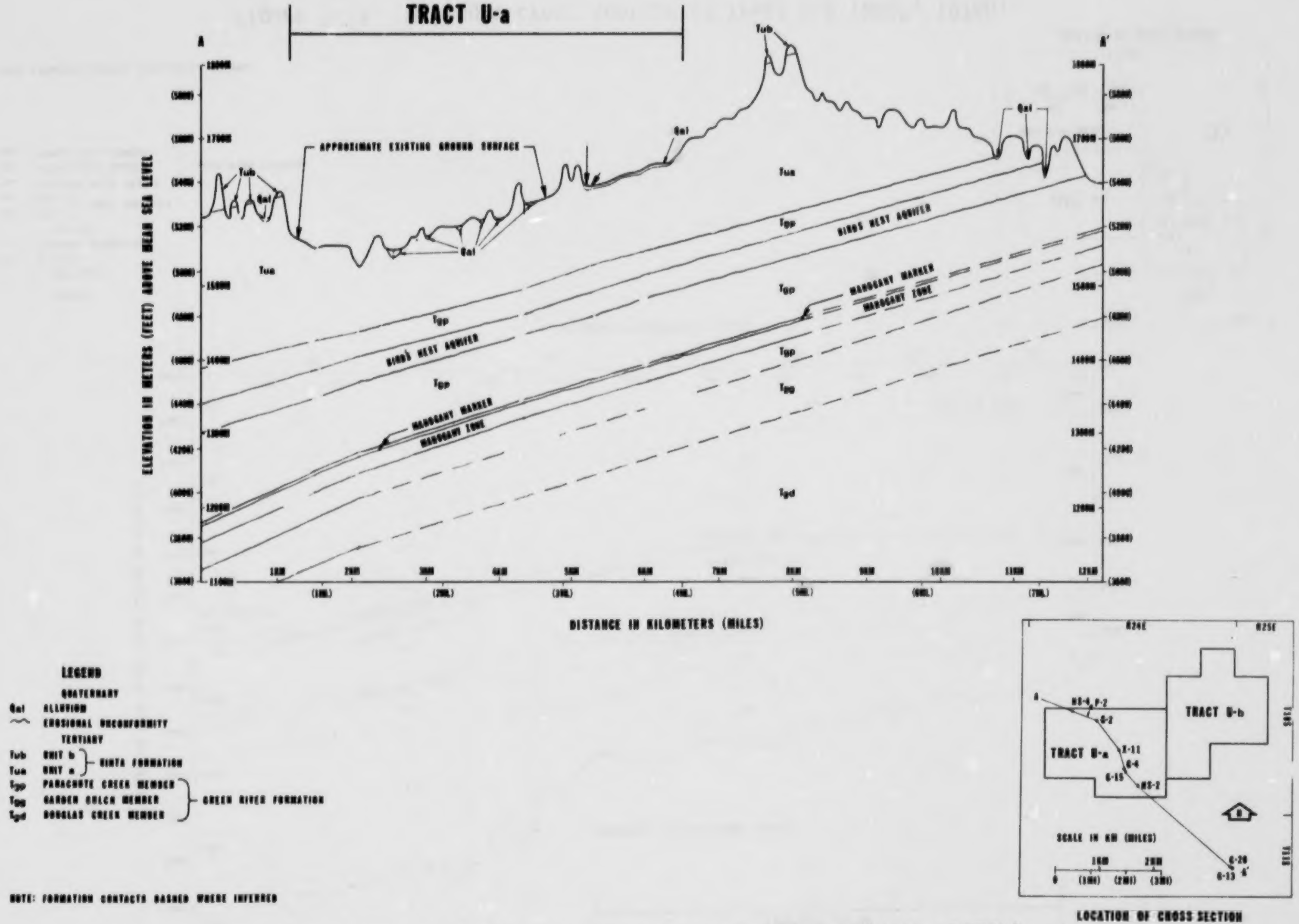

1270
1243
1250
1280
1311
1332
1341
1343
1254
1376
1378
1393
1371
1340
1344
1309
1308
1369
1401
1402
1433
1430
1443
1494
1524
1460
1421
1458
1529

Figure 5-11. Subsurface structural contour map (elevation in feet above sea level) of the Mahogany Marker Tracts U-a and U-b (data from WRSP, 1976b; map by GE–TEMPO).


LEGEND
QUATERNARY
Qal ALLUVIUM
TERTIARY
Tu UINTA FORMATION
Tgp PARACHUTE CREEK MEMBER
Tgg GARDEN GULCH MEMBER
Tgd DOUGLAS CREEK MEMBER
GREEN RIVER FORMATION
Tw WASATCH FORMATION
A
A'
OIL SHALE TRACTS, Ua-Ub
EXISTING GROUND SURFACE
WHITE RIVER
ASPHALT WASH
PROJECTED
SOUTHAM CANYON
EVACUATION CREEK
HELLS HOLE CANYON
Qal
Tu
Tgp
Tgg
Tgd
Tw
"BIRDS NEST" AQUIFER
MAHOGANY MARKER
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
5500
5000
4500
4000
3500
3000
2500
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
DISTANCE IN MILES
LOCATION OF CROSS-SECTION
OIL SHALE TRACTS Ua - Ub
SCALE IN MILES
0 1 2

NOTE: T.D. IS TOTAL DEPTH OF BORE HOLE IN FEET

Figure 5-12. Geologic cross section of Tracts U-a and U-b (WRSP, 1976b).



TRACT U-a
A
A'
APPROXIMATE EXISTING GROUND SURFACE
Tub
Qal
Tua
Tgp
BIRDS NEST AQUIFER
MAHOGANY MARKER
MAHOGANY ZONE
Tgg
Tgd
ELEVATION IN METERS (FEET) ABOVE MEAN SEA LEVEL
1800M
1700M
1600M
1500M
1400M
1300M
1200M
1100M
(5800)
(5600)
(5400)
(5200)
(5000)
(4800)
(4600)
(4400)
(4200)
(4000)
(3800)
(3600)
1KM
2KM
3KM
4KM
5KM
6KM
7KM
8KM
9KM
10KM
11KM
12KM
(1ML)
(2ML)
(3ML)
(4ML)
(5ML)
(6ML)
(7ML)
DISTANCE IN KILOMETERS (MILES)
LEGEND
QUATERNARY
Qal ALLUVIUM
EROSIONAL UNCONFORMITY
TERTIARY
Tub UNIT b
Tua UNIT a
UINTA FORMATION
Tgp PARACHUTE CREEK MEMBER
Tgg GARDEN GULCH MEMBER
Tgd DOUGLAS CREEK MEMBER
GREEN RIVER FORMATION
NOTE: FORMATION CONTACTS DASHED WHERE INFERRED
R24E
R25E
T10S
T11S
TRACT U-a
TRACT U-b
A
WS-4
P-2
G-2
X-11
G-4
G-15
WS-2
G-20
G-13
A'
N
SCALE IN KM (MILES)
0
1KM
2KM
(1MI)
(2MI)
(3MI)
LOCATION OF CROSS SECTION

Figure 5-13. Geologic cross section of Tract U-a (WRSP, 1976b).

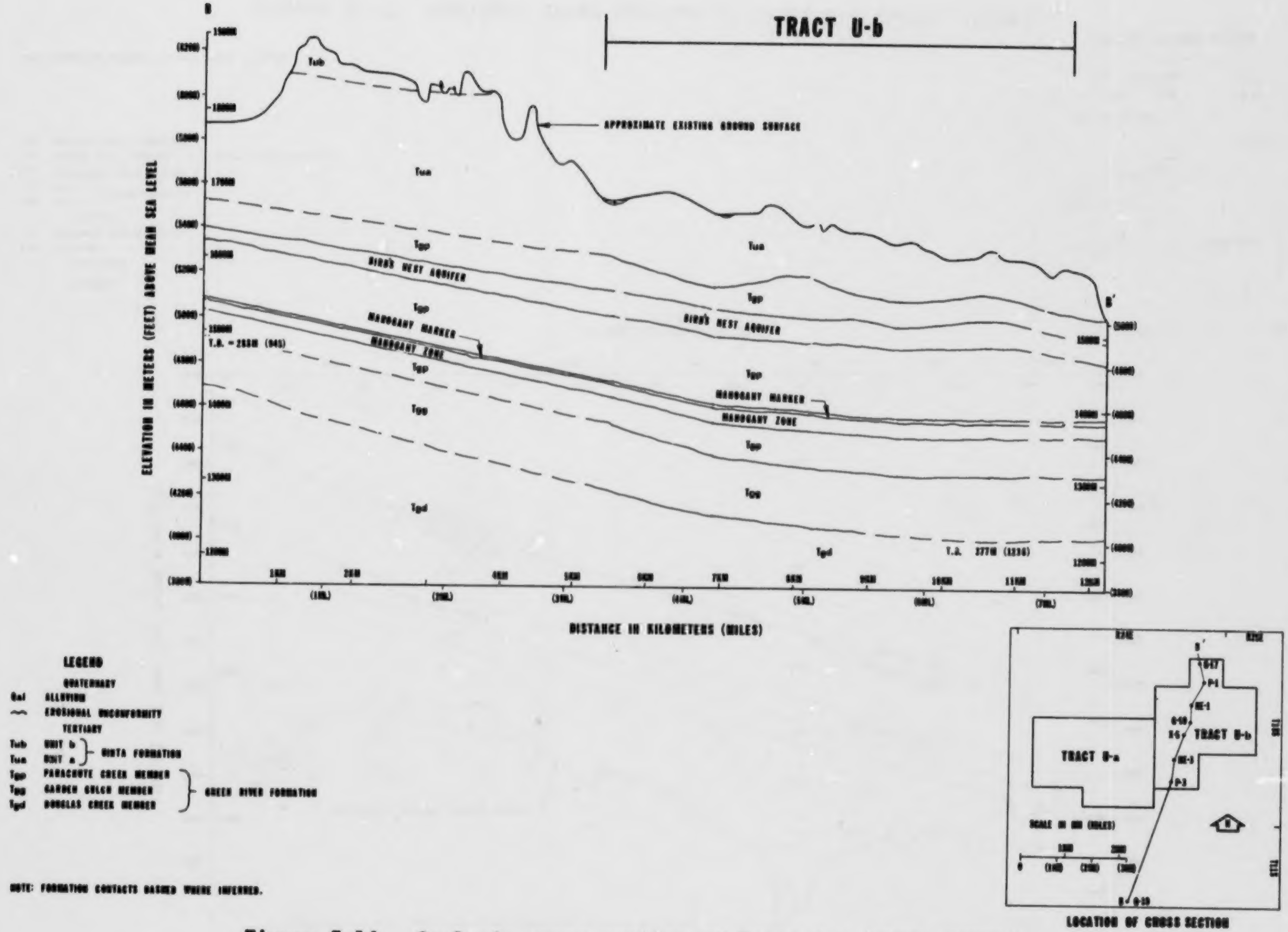

TRACT U-b
B
B'
APPROXIMATE EXISTING GROUND SURFACE
Tub
Tua
Tgp
BIRD'S NEST AQUIFER
MAHOGANY MARKER
MAHOGANY ZONE
Tgg
Tgd
T.D. = 288M (945)
T.D. 377M (1236)
ELEVATION IN METERS (FEET) ABOVE MEAN SEA LEVEL
1900M
1800M
1700M
1600M
1500M
1400M
1300M
1200M
(6200)
(6000)
(5800)
(5600)
(5400)
(5200)
(5000)
(4800)
(4600)
(4400)
(4200)
(4000)
(3800)
DISTANCE IN KILOMETERS (MILES)
1KM
2KM
4KM
5KM
6KM
7KM
8KM
9KM
10KM
11KM
12KM
(1ML)
(2ML)
(3ML)
(4ML)
(5ML)
(6ML)
(7ML)
LEGEND
QUATERNARY
Qal ALLUVIUM
EROSIONAL UNCONFORMITY
TERTIARY
Tub UNIT b
Tua UNIT a
UINTA FORMATION
Tgp PARACHUTE CREEK MEMBER
Tgg GARDEN GULCH MEMBER
Tgd DOUGLAS CREEK MEMBER
GREEN RIVER FORMATION
NOTE: FORMATION CONTACTS DASHED WHERE INFERRED.
R24E
R25E
T10S
T11S
TRACT U-a
TRACT U-b
P-1
RE-1
P-3
SCALE IN KM (MILES)
0
100
200
LOCATION OF CROSS SECTION

Figure 5-14. Geologic cross section of Tract U-b (WRSP, 1976b).

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best available copy.

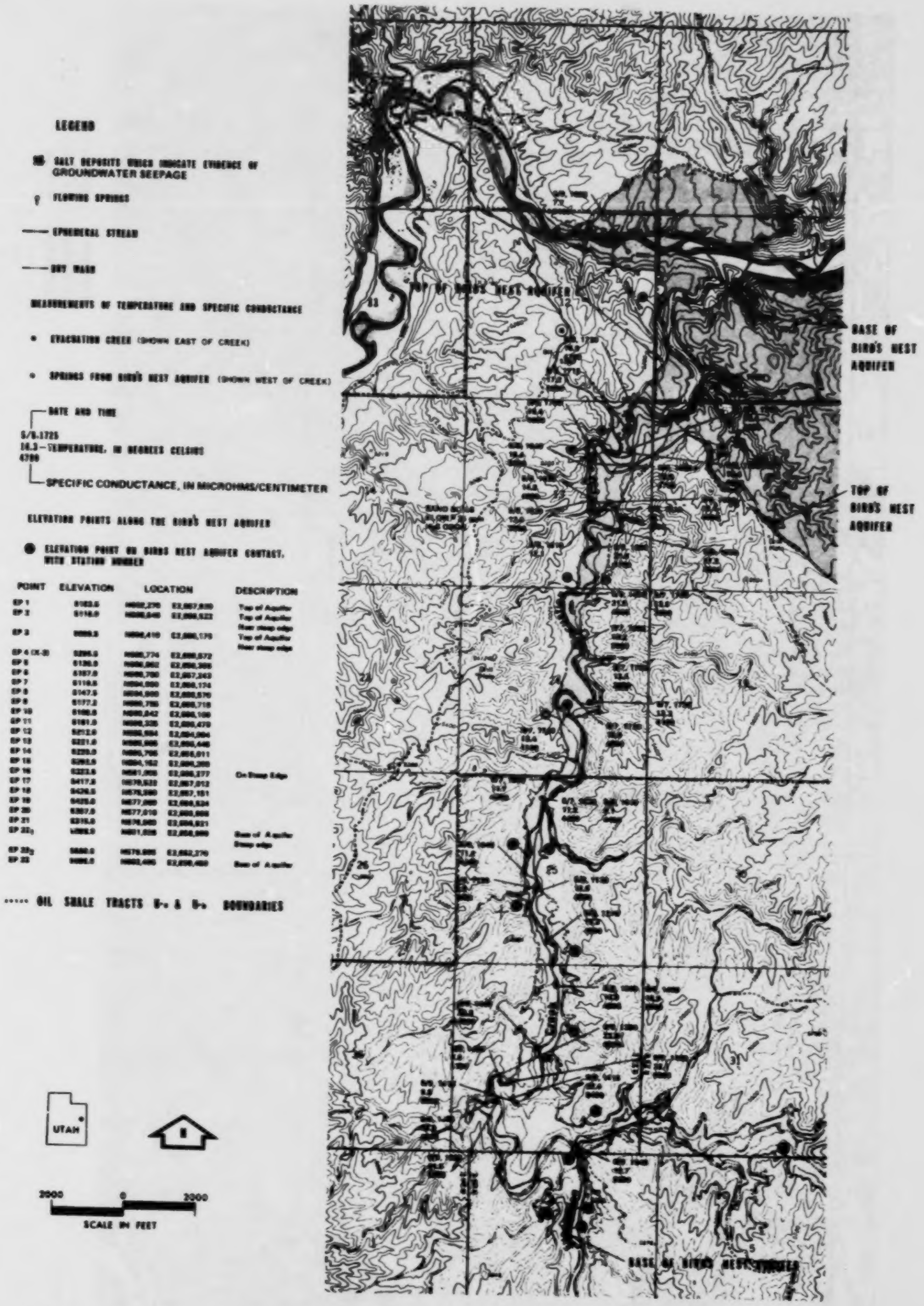
LEGEND
SALT DEPOSITS WHICH INDICATE EVIDENCE OF GROUNDWATER SEEPAGE
FLOWING SPRINGS
EPHEMERAL STREAM
DRY WASH
MEASUREMENTS OF TEMPERATURE AND SPECIFIC CONDUCTANCE
EVACUATION CREEK (SHOWN EAST OF CREEK)
SPRINGS FROM BIRD'S NEST AQUIFER (SHOWN WEST OF CREEK)
DATE AND TIME
5/8.1725
16.3 — TEMPERATURE, IN DEGREES CELSIUS
4700
SPECIFIC CONDUCTANCE, IN MICROHMS/CENTIMETER
ELEVATION POINTS ALONG THE BIRD'S NEST AQUIFER
ELEVATION POINT ON BIRDS NEST AQUIFER CONTACT, WITH STATION NUMBER
POINT
ELEVATION
LOCATION
DESCRIPTION
OIL SHALE TRACTS U-a & U-b BOUNDARIES
UTAH
2000
0
2000
SCALE IN FEET
TOP OF BIRD'S NEST AQUIFER
BASE OF BIRD'S NEST AQUIFER
TOP OF BIRD'S NEST AQUIFER
BASE OF BIRD'S NEST AQUIFER

Figure 5-15. Hydrogeologic interactions between Evacuation Creek and the Bird's Nest Aquifer (WRSP, 1976b).

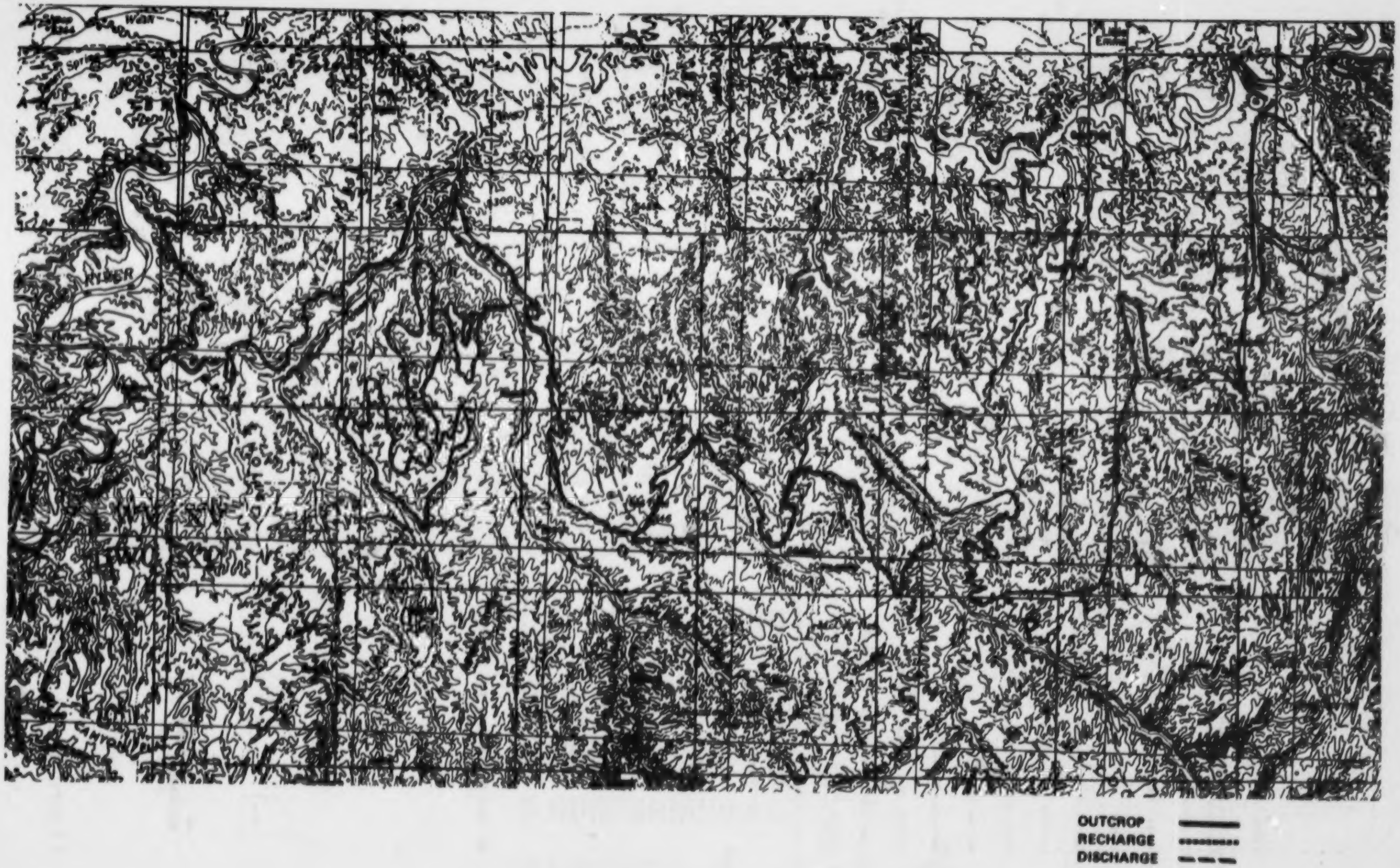
OUTCROP
RECHARGE
DISCHARGE

Figure 5-16. Bird's Nest Zone outcrop, recharge, and discharge areas.

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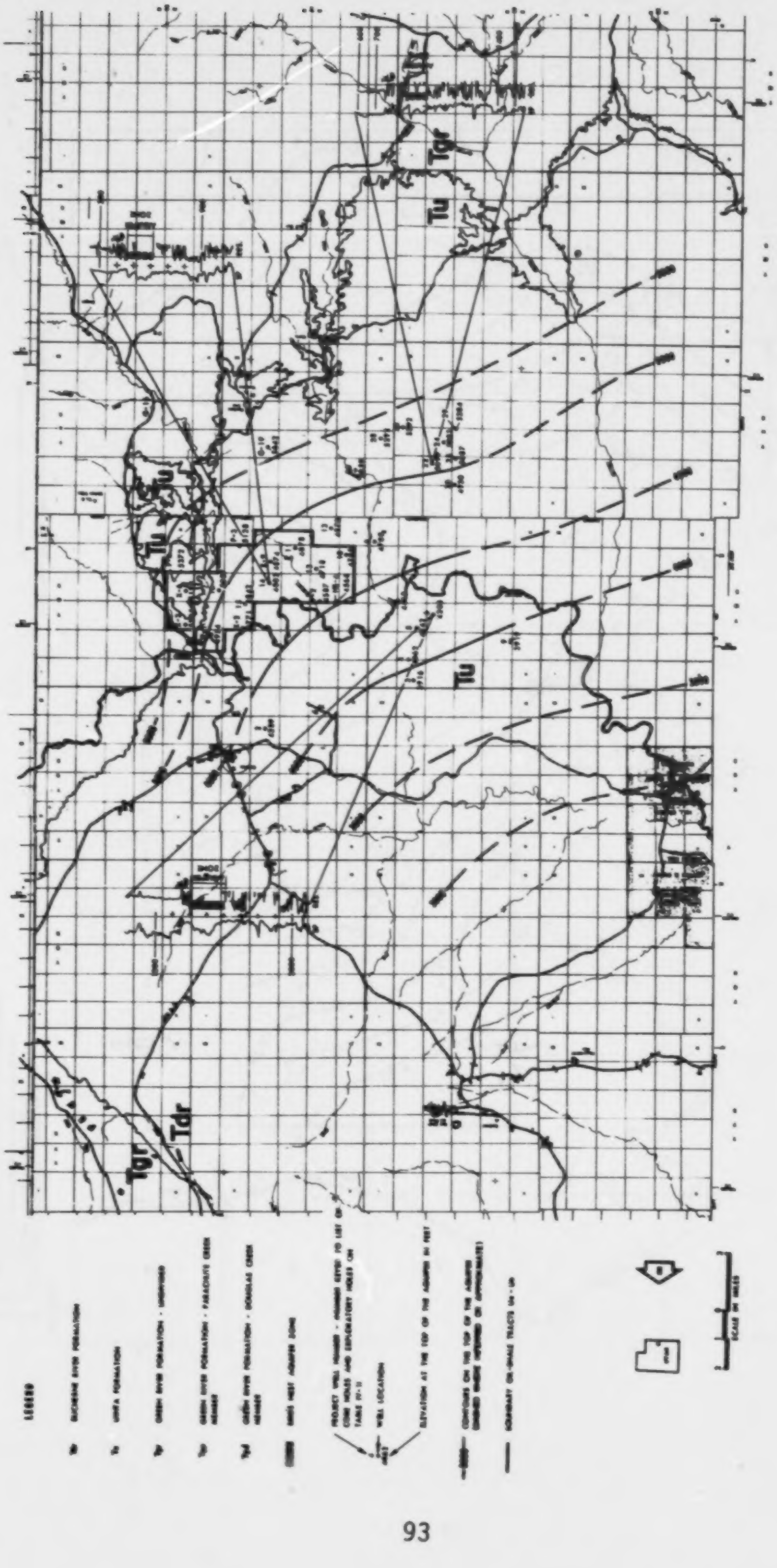

Tu
Tgr
Tdr
LEGEND

Figure 5-17. Structural contours of the top of the Bird's Nest Aquifer (WRSP, 1976b).

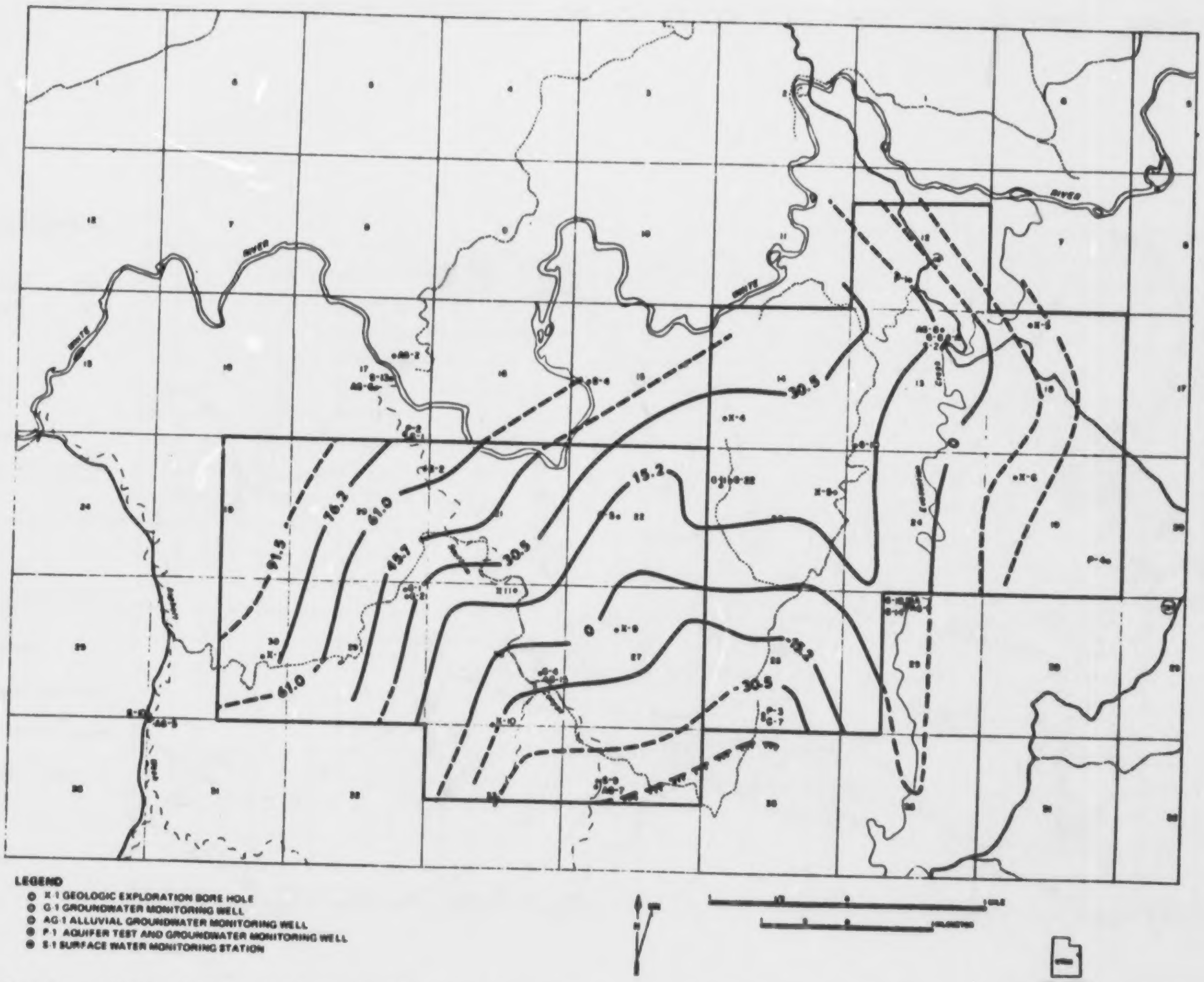

91.5
76.2
61.0
45.7
30.5
15.2
0
15.2
30.5
30.5
61.0
RIVER
WHITE
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION

Figure 5-18. Water table and artesian conditions in the Bird's Nest Aquifer. Water levels shown are in meters above the top of the aquifer (data from WRSP, 1976b; map by GE–TEMPO).

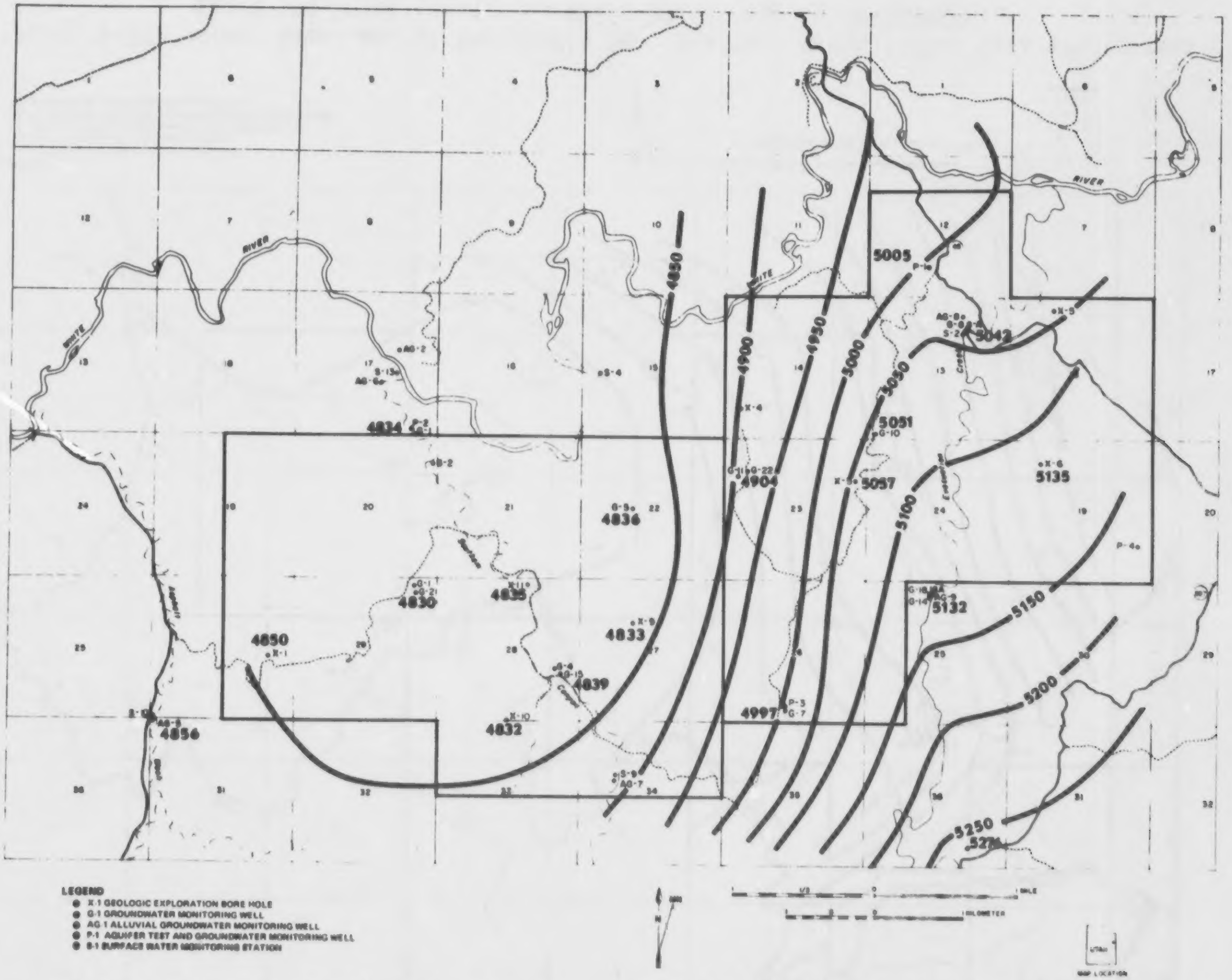
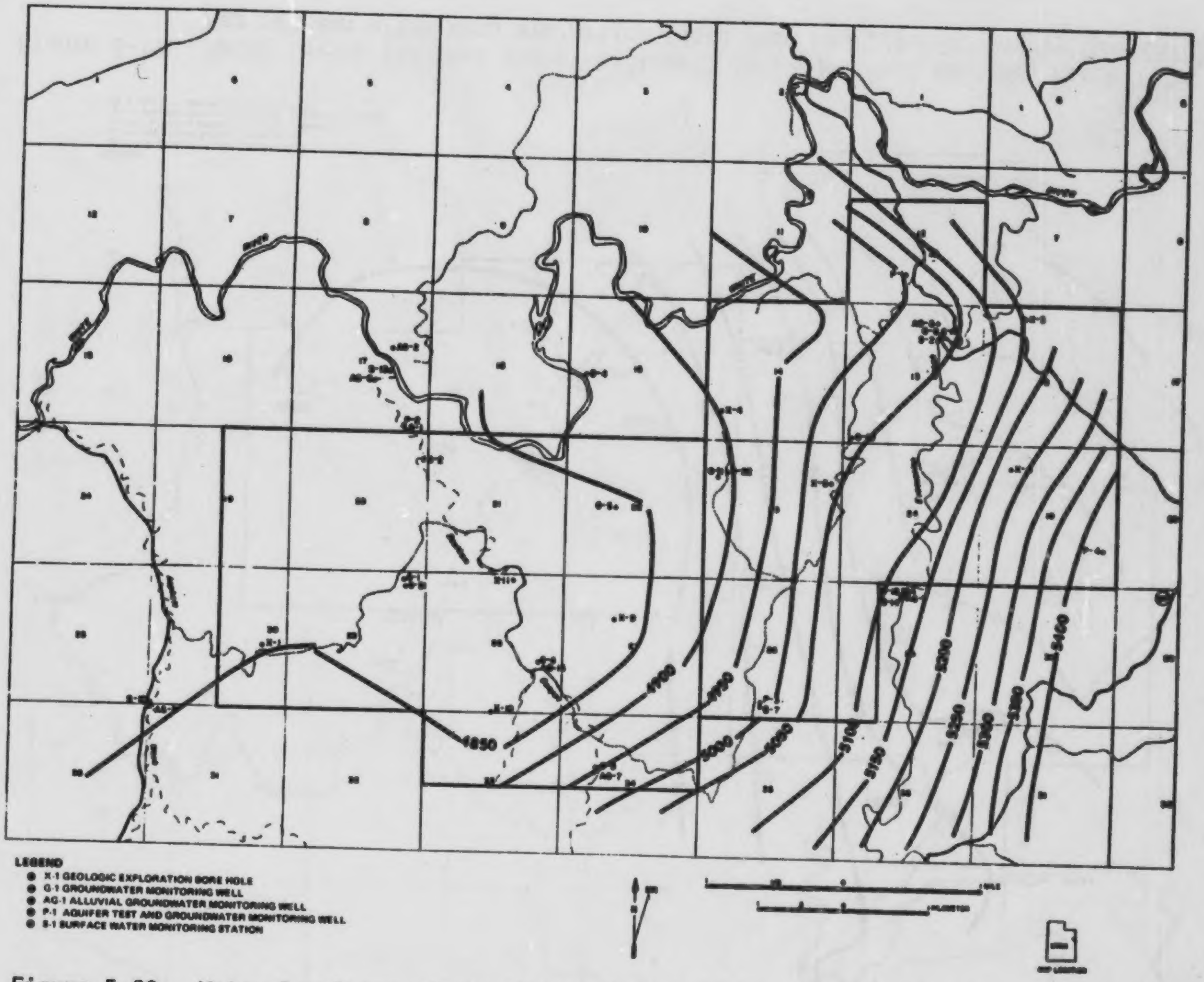

WHITE RIVER
RIVER
4850
4900
4950
5000
5050
5100
5150
5200
5250
5005
5042
5051
5057
5135
5132
4904
4997
4836
4833
4839
4832
4835
4830
4834
4850
4856
LEGEND
● X-1 GEOLOGIC EXPLORATION BORE HOLE
● G-1 GROUNDWATER MONITORING WELL
● AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
● P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
● S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
UTAH
MAP LOCATION

Figure 5-19. Water levels (in feet above sea level) in Bird's Nest Aquifer, March 1975. Map redrawn after data evaluation (data from WRSP, 1976b; map by GE-TEMPO).


4850
4900
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5400
LEGEND
● X-1 GEOLOGIC EXPLORATION BORE HOLE
● G-1 GROUNDWATER MONITORING WELL
● AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
● P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
● S-1 SURFACE WATER MONITORING STATION

Figure 5-20. Water-level map of the Bird's Nest Aquifer, March 1975. Data are in feet above sea level (data from WRSP, 1976b; map by GE—TEMPO).

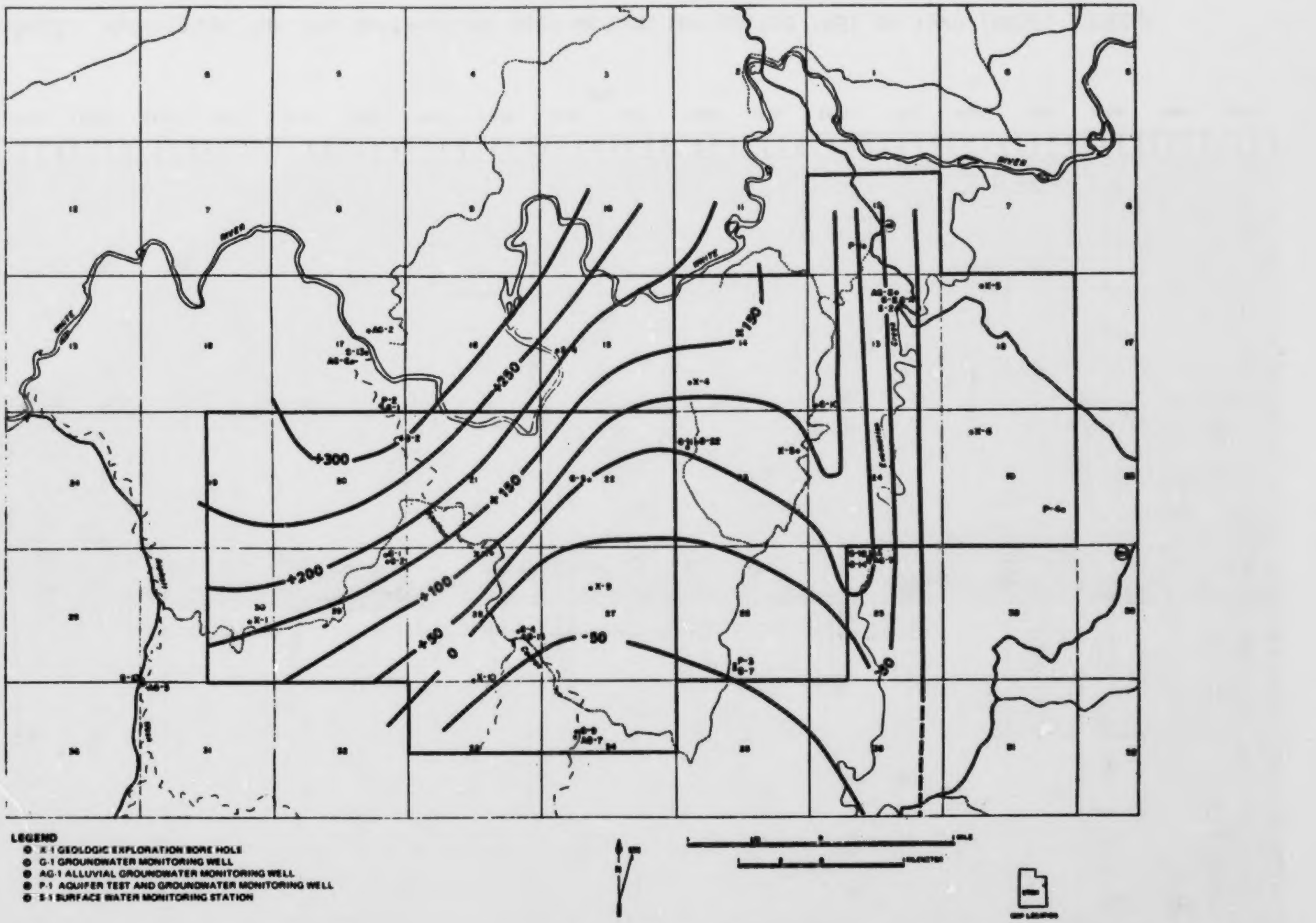

+300
+250
+200
+150
+100
+50
0
-50
+150
-50
WHITE RIVER
Evacuation Creek
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER

Figure 5-21. Water-level map of Bird's Nest Aquifer modified after data evaluation. Water levels shown are in meters relative to the top of the aquifer (data from WRSP, 1976b; map by GE—TEMPO).

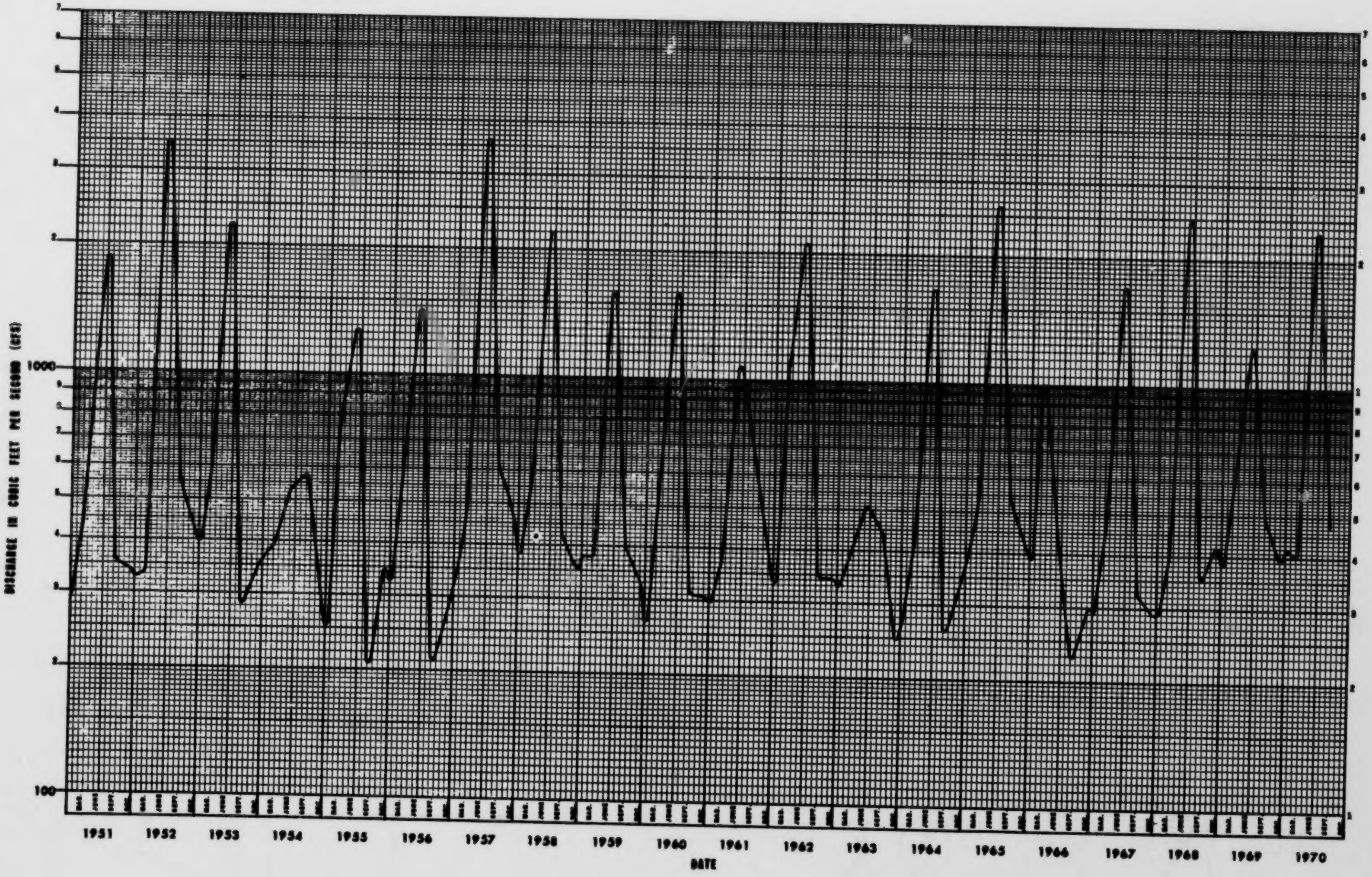


Figure 5-22. Hydrograph for the White River near Watson for period 1951 to 1970 (WRSP, 1976b).

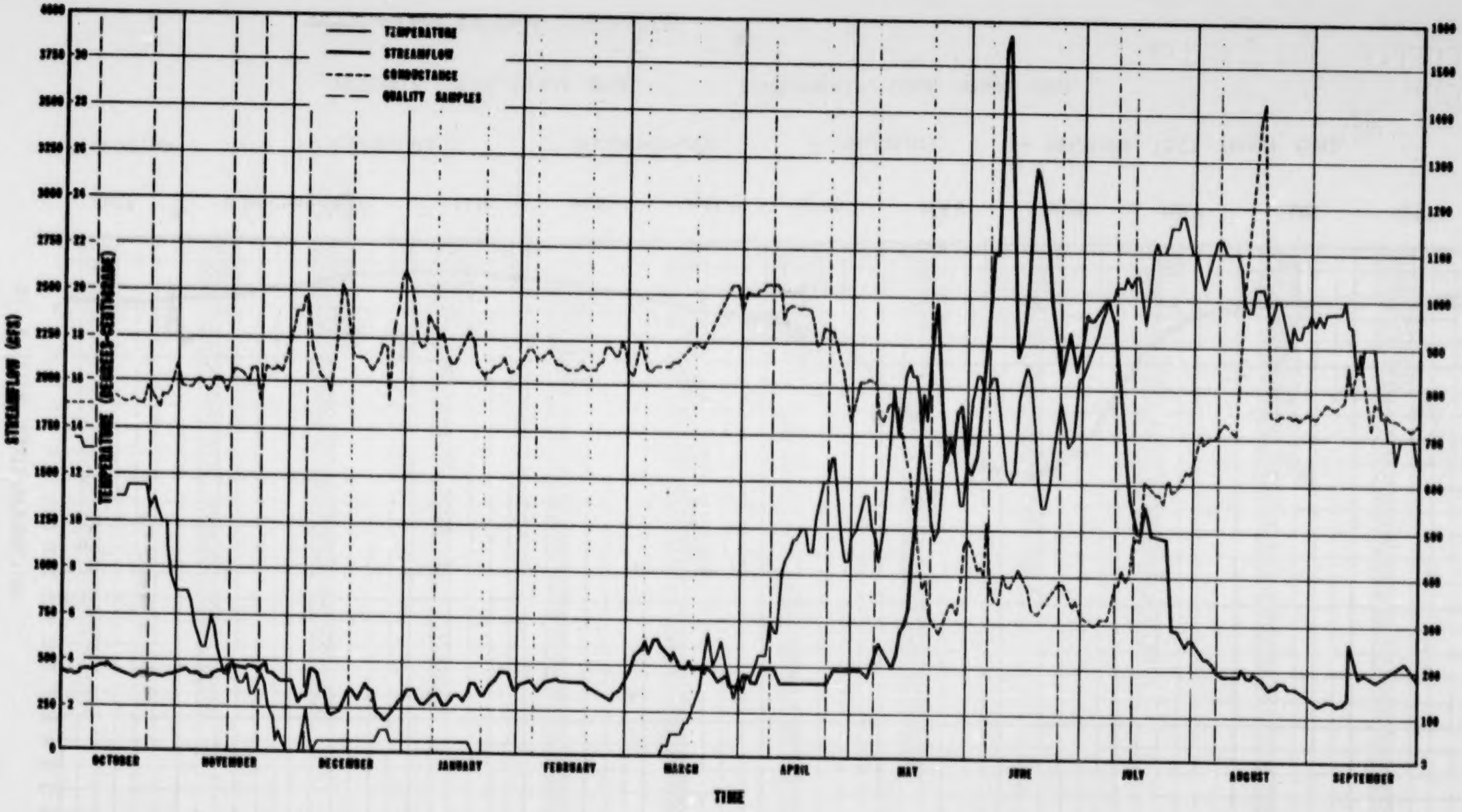


Figure 5-23. Mean daily streamflow, temperature, and specific conductance measured in the White River above Southam Canyon, October 1974–September 1975 (WRSP, 1976b).

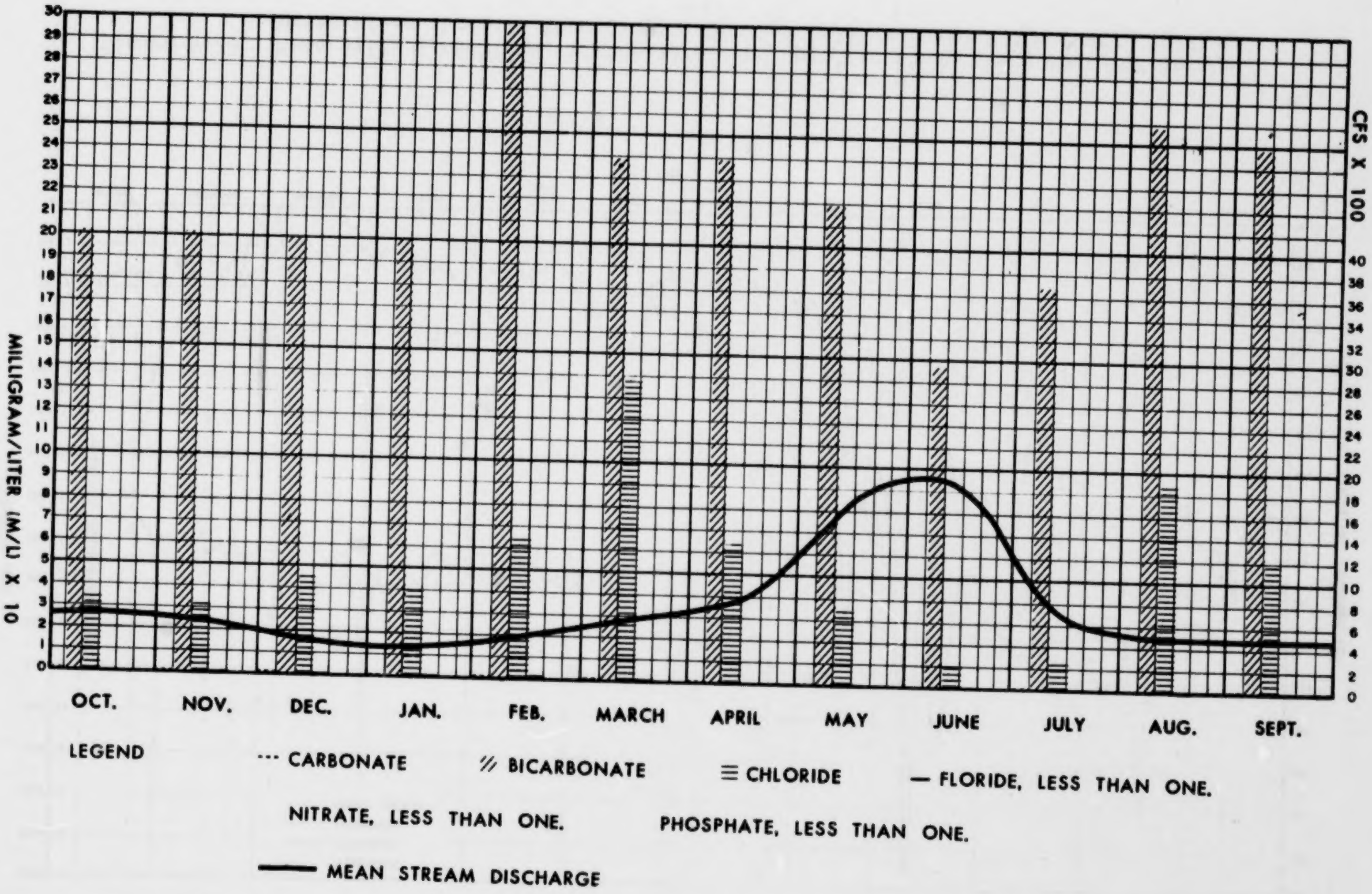


Figure 5-24. Mean carbonate, bicarbonate, and chloride concentrations of the White River near Watson. (Fluoride, nitrate, and phosphate concentrations were all less than 1 mg/l.) (WRSP, 1976b)

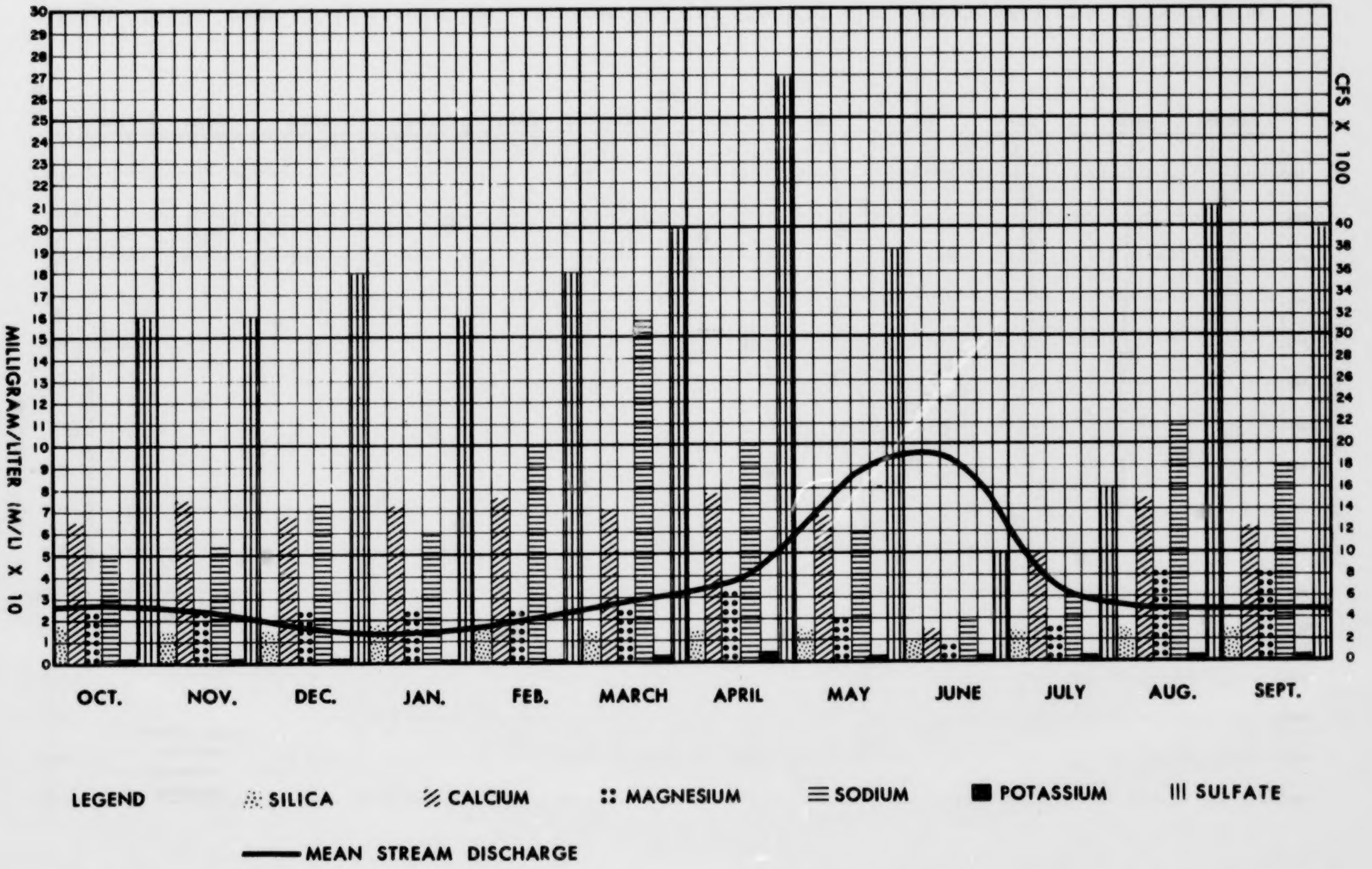


Figure 5-25. Mean water quality of the White River near Watson, Utah (WRSP, 1976b).

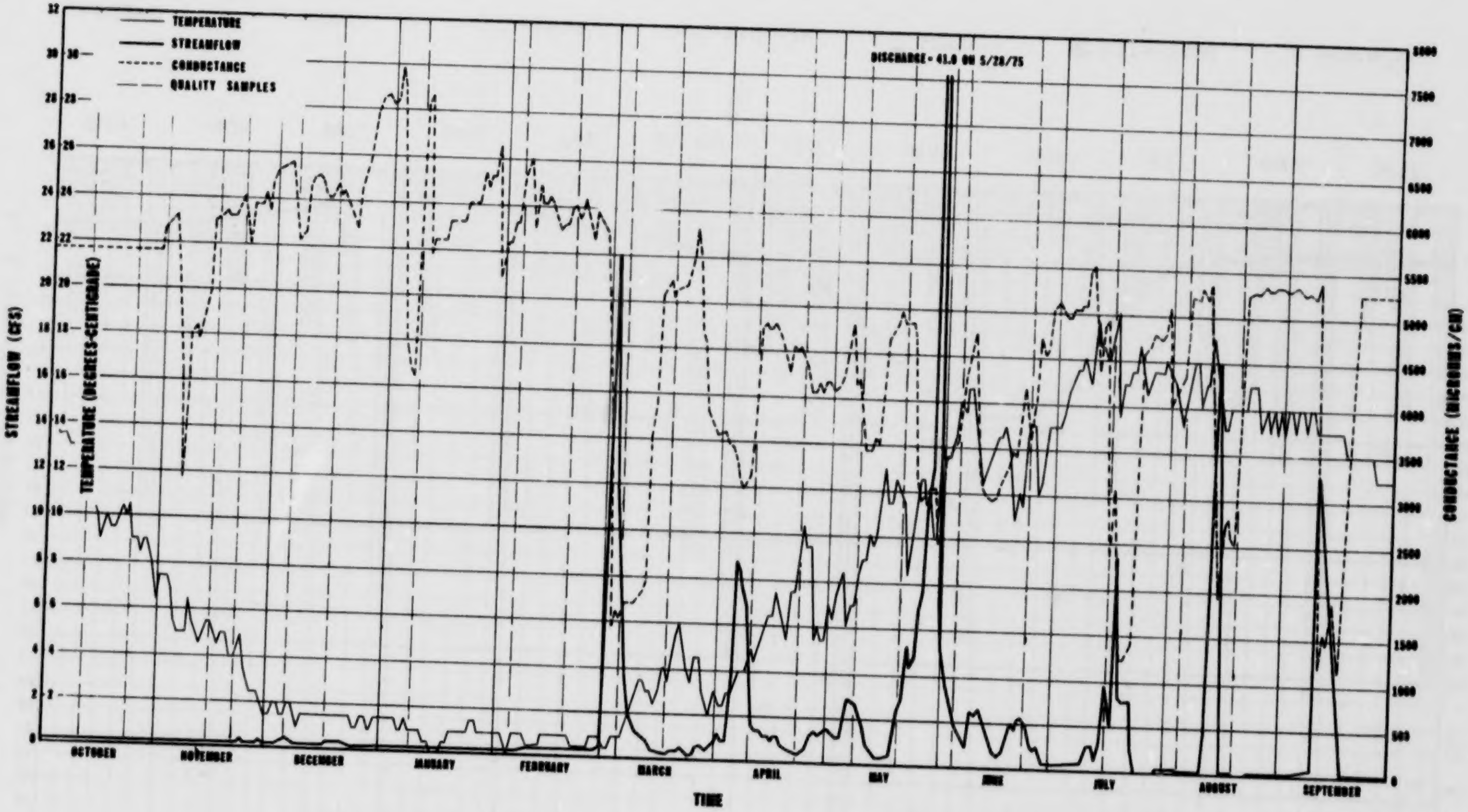


Figure 5-26. Mean daily streamflow, temperature, and specific conductance measured in Evacuation Creek at Watson, Utah, October 1974–September 1975 (WRSP, 1976b).

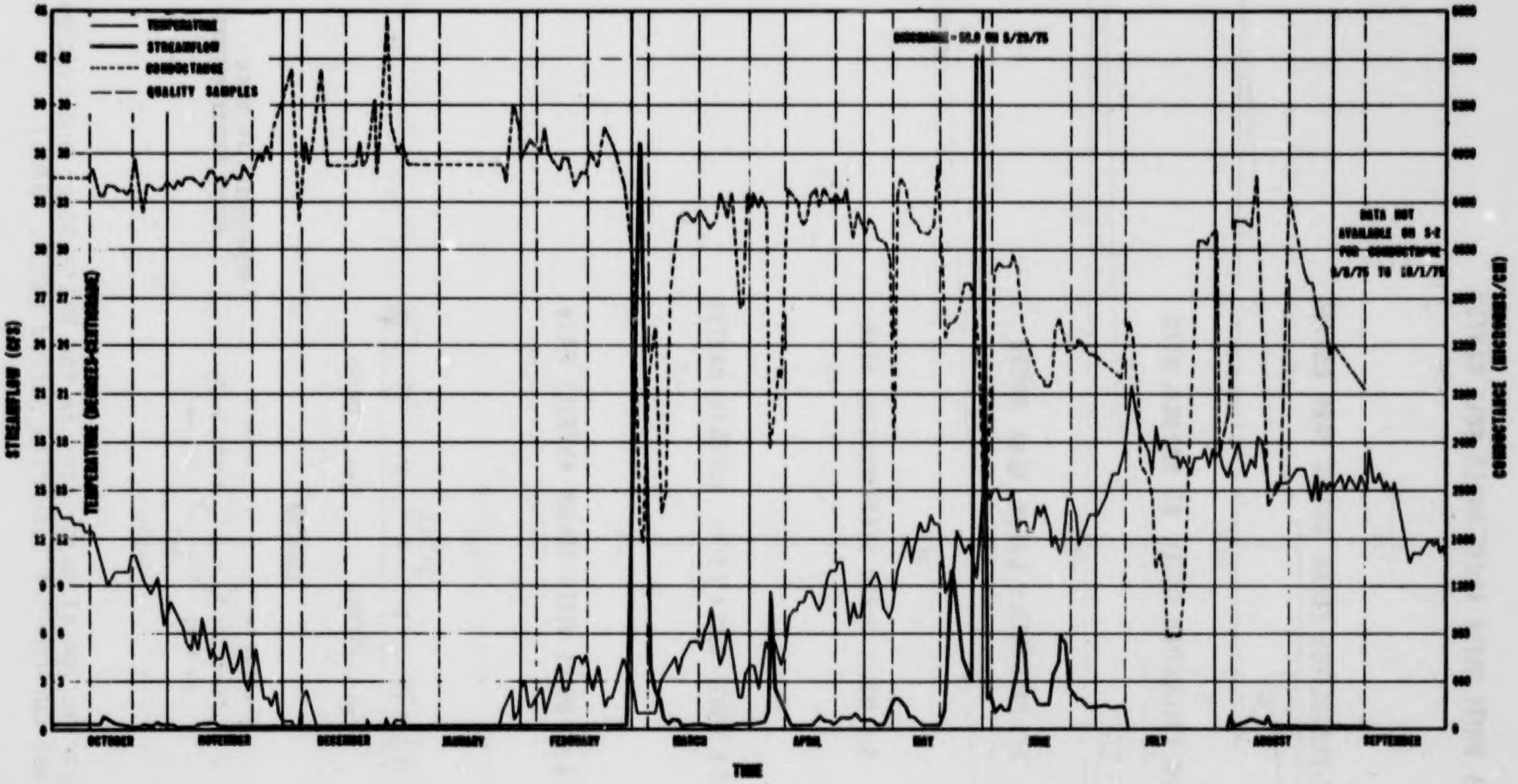


Figure 5-27. Mean daily streamflow, temperature, and specific conductance measured near the mouth of Evacuation Creek, October 1974–September 1975 (WRSP, 1976b).

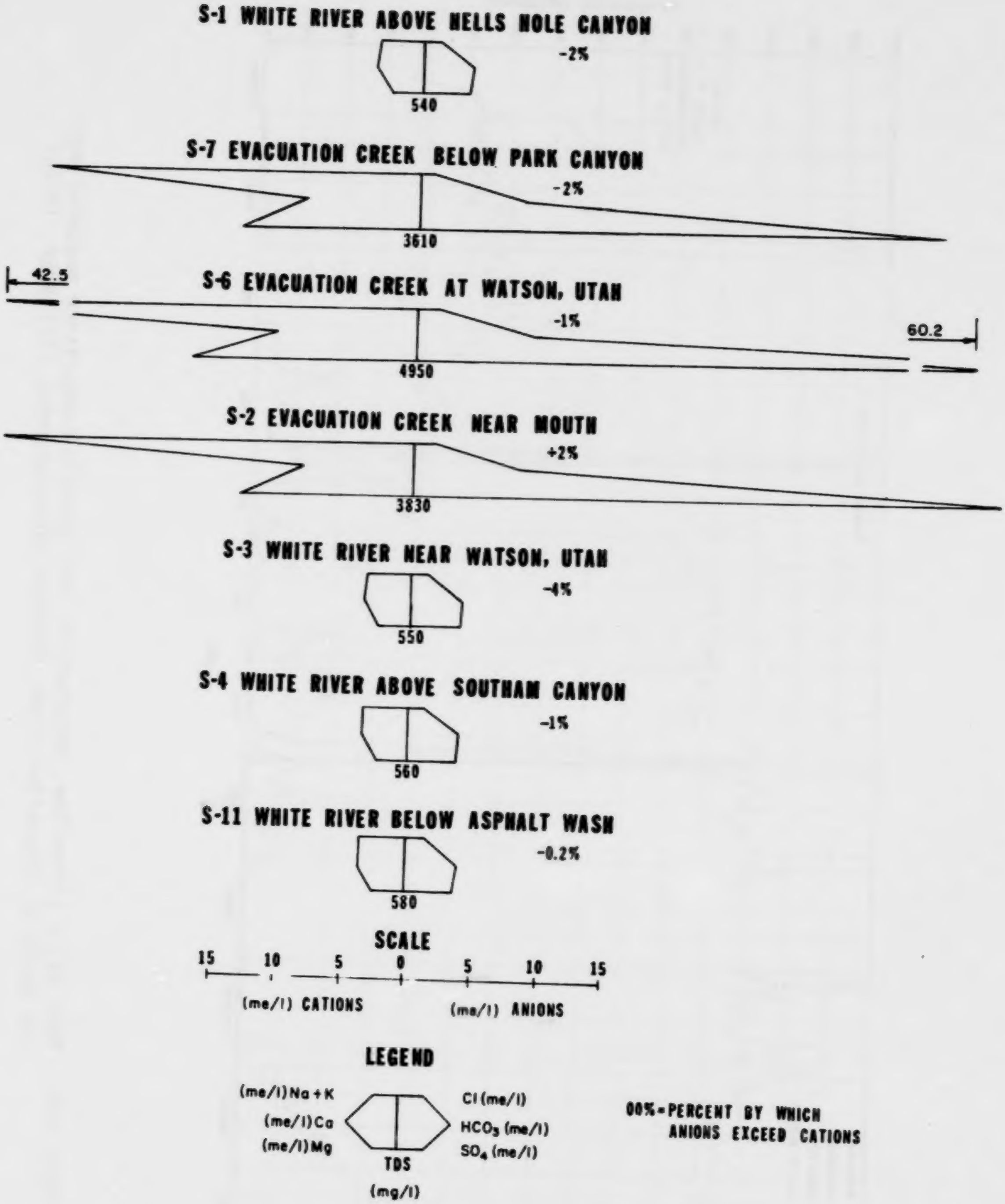


Figure 5-28. Distribution of major ions in the White River and Evacuation Creek during 1975 base flow period (WRSP, 1976b).

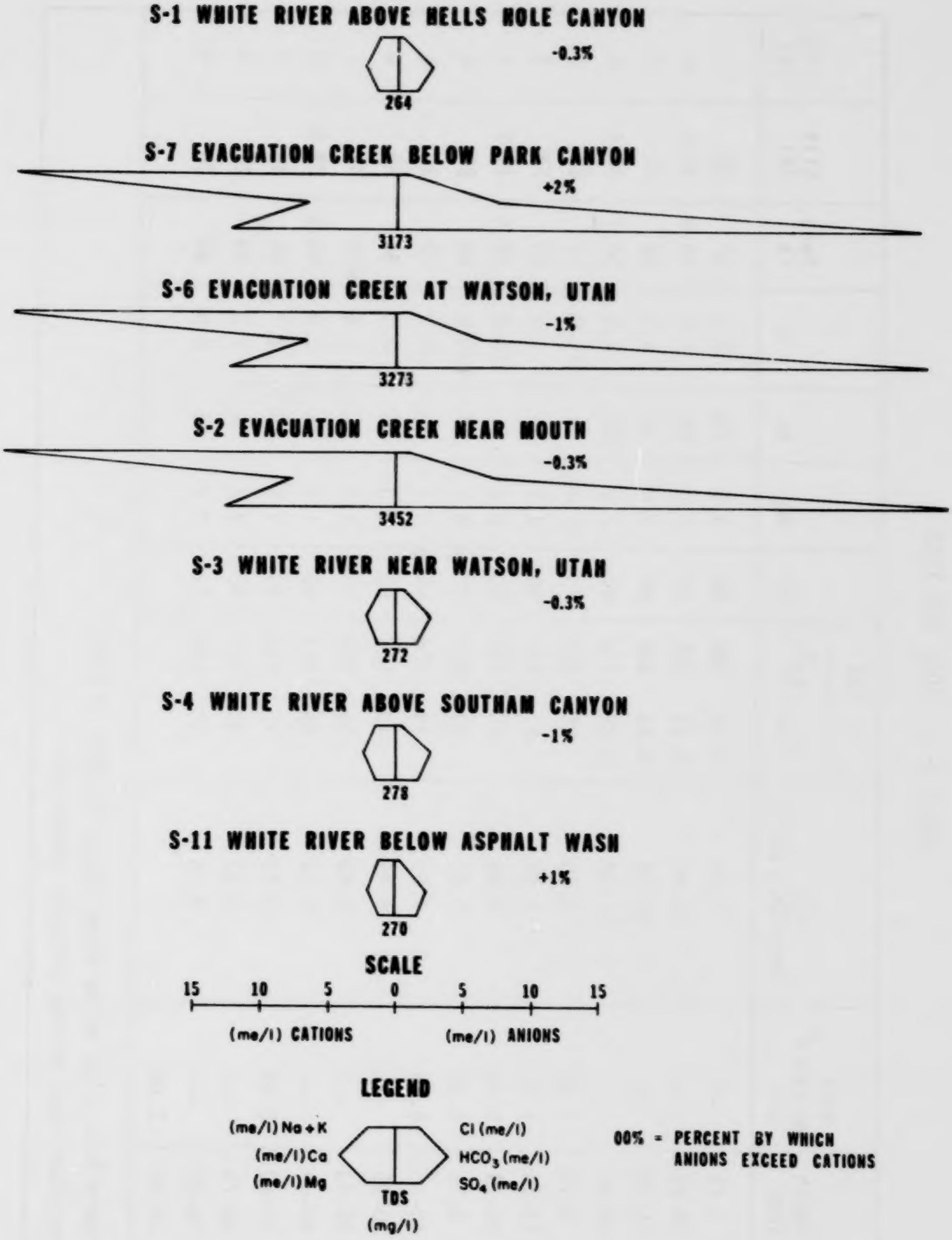


Figure 5-29. Distribution of major ions in the White River and Evacuation Creek during May through July 1975 high flow period (WRSP, 1976b).

TABLE 5-1. SOIL ANALYSES

Soil[a]	Depth (cm)	Soil moisture[b] (%)	CEC (meq/100 g soil)	TSS		Ca	Mg	Na	K	Sand (%)	Silt (%)	Clay (%)
				($Ec_e \times 10^3$)								
As	0-15	---	9.80	0.52	364	80	3.5	20	3.5	57	35	8
	15-25	---	10.98	0.43	301	63	3.0	29	2.5	56.6	35.4	8
	25-30	---	10.88	0.64	448	48	3.0	84	3.5	58	35	7
	30-35	---	11.30	1.02	714	44	2.9	132	2.5	55.5	36.5	8
Bs-4	0-10	1.26	5.65	.80	560	75	11.4	34	75.0	71	23	6
	10-20	1.43	8.93	.61	427	60	4.1	56	3.5	69	27	4
	20-30	3.78	9.80	.50	350	50	2.3	61	20.0	68.5	29.5	2
D	0-10	4.33	5.45	.94	658	62	8.1	44	130.0	64	28	8
	10-20	6.33	7.18	.44	308	44	3.1	30	25.0	69	25	6
	20-30	---	9.45	.43	301	50	2.0	35	2.0	58	38	4
	30-40	---	10.88	.36	252	38	1.8	36	2.4	58	41	1
	40-50	---	9.03	.29	203	45	1.0	36	2.0	65.5	32.5	2
	50-60	2.25	9.13	.35	285	99	1.5	45	2.7	66	30	4
	60-70	---	9.03	.42	294	40	2.2	50	3.5	69	27	4
	70-80	---	9.75	.37	259	31	2.2	46	2.8	68	28	4
	25-45	2.60										

[a] See Figure 5-5, also White River Shale Project (1976b)

[b] Some moisture loss during shipping suspected

TABLE 5-2. AQUIFER PUMP TEST RESULTS (WRSP, 1976b)

Test No./ Pump rate/ Pump time	Observation well distance from pumping well (r) in meters (feet)	Observation well designation	Method of analysis	Period of test	Calculated aquifer coefficients	
					Transmissivity, T 1/s/m (gal/day/ft)	Storage
P-1 Test Q=2.839 1/s (45 gal/min) Duration of pumping = 1800 min	---	P-1 pump	Time-drawdown (Jacob)	Pumping	0.344 (2475) (early slope) 0.209 (1458) (late slope)	--- ---
	15.85 (52.0)	P-1 pilot	Time-drawdown (Jacob)		0.131 (914) (early slope) 0.234 (1627) (late slope)	3.55×10^{-4} ---
			Residual drawdown	Recovery	0.140 (972)	---
			Calculated recovery drawdown vs. radius		0.147 (1024) 0.259 (1800)	3.40×10^{-4}
	30.94 (101.5)	P-1 core	Time-drawdown (Jacob)	Pumping	0.257 (1789)	3.80×10^{-4}
			Residual drawdown	Recovery	0.228 (1584)	---
P-2 Upper Test Q=0.631 1/s (10 gal/min) Duration of pumping = 1676 min		P-2 upper pump	Time-drawdown (Jacob)	Pumping	0.017 (120) (early slope) 0.004 (27) (middle slope) 0.002 (15) (late slope)	--- --- ---
	14.63 (48.0)	P-2 upper pilot	Time-drawdown (Jacob)	Pumping	0.017 (120) (early slope) 0.004 (27) (middle slope) 0.002 (15) (late slope)	1.6×10^{-5} --- ---
			Residual drawdown	Recovery	0.004 (25) (middle slope)	---
	29.87 (98.0)	P-2 upper core	Time-drawdown (Jacob)	Pumping	0.018 (123) (early slope) 0.005 (36) (middle slope) 0.002 (17) (late slope)	1.07×10^{-5} --- ---
			Residual drawdown	Recovery	0.004 (28) (middle slope)	---

(continued)

TABLE 5-2 (continued)

Test No./ Pump rate/ Pump time	Observation well distance from pumping well (r) in meters (feet)	Observation well designation	Method of analysis	Period of test	Calculated aquifer coefficients	
					Transmissivity, T 1/s/m (gal/day/ft)	Storage
P-2 Lower Test Q=34.696 1/s (550 gal/min) Duration of Pumping = 8765 min		P-2 lower pump		Pumping Recovery	--- ---	--- ---
	14.81 (48.0)	P-2 lower pilot	Time-drawdown (Jacob)	Pumping	8.984 (62,586) (early slope) 16.043 (111,692)(late slope)	6.77 x 10^{-6} ---
			Calculated recovery	Recovery	9.935 (69,173)	1.14 x 10^{-5}
			Residual drawdown		9.935 (69,173)	---
	28.93 (94.9)	P-2 lower core	Time-drawdown (Jacob)	Pumping	9.068 (63,130)(early slope) 14.897 (103,714)(late slope)	8.29 x 10^{-5} ---
			Calculated recovery	Recovery	9.841 (68,514)	3.13 x 10^{-5}
			Residual drawdown		9.523 (66,304)	---
		P-2 lower core & pilot	Distance-drawdown drawdown vs. radius	Pumping	9.959 (69,339) 10.701 (74,500)	1.68 x 10^{-4}
P-3 Test Q=0.189 1/s (3 gal/min) Duration of pumping = 30 min		P-3 pump	Time-drawdown (Theis)	Pumping	0.0080 (58)	0.105
			Time-drawdown (Jacob)		0.009 (61) (early slope) 0.004 (26) (late slope)	0.085 ---
			Residual drawdown	Recovery	--- (6.7)	---

TABLE 5-3. WATER BALANCE WITHIN TRACT FOR WATER YEAR 1975, SOUTHAM CANYON, cm (inches)

Time period	Average precipitation	Total runoff	Soil storage change[a]	Total evapotranspiration	Percent evapotranspiration (%)	Pan evaporation	Pan coefficient[b]	Potential evaporation[c]
Oct. 1974 through April 1975	12.67 (4.99)	0.15 (0.06)	0 (0)	12.52 (4.93)	98.9			
May 1975 through Sept. 1975	12.34 (4.86)	0 (0)	0 (0)	12.34 (4.86)	100.0	99.62 (39.22)	0.70	69.73 (27.45)
Oct. 1974 through Sept. 1975	25.02 (9.85)	0.15 (0.06)	0 (0)	24.87 (9.79)	99.4			

[a] Assumed to be in static condition or zero change.

[b] Average coefficient suggested by Vente Chow: "Handbook of Applied Hydrology" to account for radiation effects on pan.

[c] Potential free surface evaporation which is comparable to the potential consumptive use factor.

TABLE 5-4. ESTIMATED PEAK STREAMFLOWS FOR HELLS HOLE CANYON, SOUTHAM CANYON, AND ASPHALT WASH, m^3/s (ft^3/s)

Drainage	Method	2 Yr	5 Yr	10 Yr	25 Yr	50 Yr	100 Yr
Hells Hole Canyon	USGS[a]	1.6 (55)	2.8 (100)	4.0 (140)	5.9 (2.0)	7.6 (270)	
	USGS[b]	1.3 (47)	2.5 (87)	3.3 (116)	3.9 (137)		
	SCS[c]	3.2 (115)	2.6 (924)	40 (400)	46 (1600)	58 (2100)	70 (2500)
Southam Canyon	USGS[a]	0.6 (21)	1.1 (39)	1.6 (55)	2.2 (80)	3.0 (105)	
	USGS[b]	0.3 (12)	.7 (25)	1.1 (38)	1.2 (41)		
	SCS	1.1 (40)	9.1 (320)	14 (480)	16 (560)	20 (720)	24 (850)
Asphalt Wash	USGS[a]	4.0 (140)	6.8 (240)	10 (360)	15 (540)	19.8 (700)	
	USGS[b]	4.0 (140)	7.5 (263)	10 (360)	12 (470)		
	SCS[c]	12 (400)	100 (3600)	155 (5300)	180 (6200)	220 (8000)	270 (9550)

[a] Regional drainage method.

[b] General characteristics method.

[c] Soil Conservation Service method modified for limited data.

SECTION 6

EXISTING GROUNDWATER QUALITY

GENERAL GROUNDWATER QUALITY

Bird's Nest Aquifer

The chemical composition of the groundwater in the Bird's Nest Aquifer beneath Oil Shale Tracts U-a and U-b can be characterized as varying from sodium sulfate to sodium bicarbonate. Figure 6-1 is a plot of the yearly mean of analyses from wells in the Bird's Nest Aquifer. These analyses are generalized into two groups in Figure 6-2. The area labeled "NE" contains analyses from wells near well P-1 in the northern half of Tract U-b, and the area "SW" contains analyses from wells in Tract U-a. The well samples from the SW group contain a higher percentage of magnesium and bicarbonate than do the samples from the NE group.

This division into water quality groups corresponds to another division. If the water samples are divided on the basis of total dissolved solids (TDS) concentration, all of the analyses labeled SW will fall below 2,000 mg/l. Those labeled NE will fall above 2,000 mg/l, and most of them above 3,000 mg/l.

In summary, the NE group is characterized by a TDS content of between 4,500 mg/l and 2,500 mg/l, and a sodium-sulfate composition. Magnesium is minor (<30 percent), and the TDS content may be up to 20 percent calcium. Chloride is very minor, but up to 30 percent of the anions may be bicarbonate. In contrast, the TDS content of the SW group lies between 1,300 mg/l and 1,700 mg/l, and the composition is sodium bicarbonate. The cation composition is nearly pure sodium, while the anions may include up to 50 percent sulfate and 30 percent chloride.

Several wells (G-8, G-12, and G-14) do not fall into either group, but lie between them. The chemical composition of water from these wells is intermediate between that of the NE and SW groupings. All of these wells penetrate the Bird's Nest Aquifer beneath Evacuation Creek. The dissolved solids levels also lie between that of the NE and SW groups.

The general explanation of the groundwater quality is not difficult. The Bird's Nest Aquifer is formed of solution cavities left after the dissolution of nahcolite ($NaHCO_3$) crystals imbedded in a marlstone matrix. Thus sodium bicarbonate water would be created during the dissolution process by which the aquifer was created, and by the dissolution of any residual nahcolite after the initial process. Since the marlstone matrix of the aquifer is formed of fine grains of dolomite and calcite, some magnesium and calcium could also be expected. The only remaining major ion is sulfate. Evacuation Creek is probably the source of the sulfate in the Bird's Nest Aquifer water. Analyses of water from Evacuation Creek and its alluvium show that 75 to 85 percent of the anions are sulfate (Figure 6-2).

Douglas Creek Aquifer

Wells P-4 and G-16A are reported to penetrate the Douglas Creek Member of the Green River Formation. Water from well P-4 has lower TDS than either the Bird's Nest NE or SW and is sodium bicarbonate-chloride in composition (Figure 6-3). The P-4 water was analyzed once during 1975 and the cation analyses may be in error. The G-16A anion analyses do not agree with the P-4 analyses, but this difference may be explained by the large distance (11 kilometers or 7 miles) between the two wells.

P-2 Aquifer

The small isolated aquifer found above the Bird's Nest Aquifer at well P-2 contains sodium bicarbonate water—nearly pure dissolved nahcolite.

Alluvial Aquifers

Figure 6-2 shows one other group of analyses: those from Evacuation Creek and the alluvium beneath it. The composition of Evacuation Creek water is similar to that of the NE Bird's Nest Aquifer, but with a slightly lower sodium and bicarbonate content. The TDS concentration, varying from 4,950 mg/l to 3,830 mg/l, is comparable to the NE Bird's Nest Aquifer.

WATER QUALITY DISTRIBUTION

The spatial distribution of the major water quality constituents in the Bird's Nest Aquifer is discussed in the following paragraphs. The data plotted and described are the means of the 1974 and 1975 data collections. During this period, six to eight samples were collected from "P" wells and one to five were collected from "G" wells. Detailed data are presented in White River Shale Project (1976b).

In general, the distribution of TDS concentration is typical of the individual dissolved constituents. The NE Bird's Nest Aquifer region of poor water quality is clearly delimited. The SW region of better water quality can be seen to extend across the southern corner of Tract U-b (Figure 6-4). An interesting feature is the decrease in dissolved solids concentration along Evacuation Creek between Watson and the Highway 45 crossing. Another interesting phenomenon is the low TDS area underlying Tract U-a that is downgradient (Figure 6-5) of the Evacuation Creek recharge area.

Calcium and magnesium concentration distributions reflect the same pattern as the TDS distribution (Figures 6-6 and 6-7). The sodium plus potassium map (Figure 6-8) is also similar, but the area of high concentration is larger and less well defined. This pattern may result from the presence of sodium, in the form of nahcolite, throughout the aquifer.

The distribution of sulfate concentrations very closely follows that of the total dissolved solids (Figure 6-9). The distribution of carbonate and bicarbonate does not (Figure 6-10). Again, this fact may indicate that while the source of sodium and bicarbonate is the nahcolite within the aquifer, the source of the larger part of the other ions is from outside the aquifer, from Evacuation Creek.

Both bicarbonate and chloride concentrations show an anomalous distribution. In the case of carbonate plus bicarbonate, there exists a long, narrow zone of higher concentration extending northwest from Evacuation Creek. This zone extends in a direction perpendicular to the equipotential lines (Figure 6-5), suggesting a plume moving down gradient from a source along Evacuation Creek.

The distribution of chloride concentration is even more anomalous (Figure 6-11). A north-south zone of slighly higher concentration exists along the boundary between the tracts, with well G-5 possessing a consistent concentration nearly four times that of any other well. This high concentration is unexplained, but does not seem to be of regional significance. The chloride concentration in the rest of the aquifer and Evacuation Creek is low, and it probably reflects nothing more than slight differences in chloride content of the rock forming the aquifer.

The aquifer temperature distribution (Figure 6-12) is informative. Cold water in a zone along Evacuation Creek reflects both recharge of cold stream water and seasonal cooling of the near-surface aquifer water. The aquifer is progressively more deeply covered toward the west and the water is warmed by geothermal heat as it flows. This temperature distribution strongly supports the idea of recharge from Evacuation Creek.

Another significant feature is the lower temperature at well P-2L located near the White River just north of Tract U-a. Figures 6-13 through 6-16 are successive temperature distributions through the two years for which data are available. Although the data for March 1975 are missing, lower winter than spring temperatures are indicated. During May the average temperature of the White River is 11° C (52° F), while during November it is 3° C (36° F). This correlation of river and aquifer temperatures supports the possibility of recharge of the Bird's Nest Aquifer in the region of well P-2L by downward leakage from the White River.

Figures 6-17 through 6-24 illustrate the concentration of TDS and sulfate at various times. Unfortunately, lack of uniform sampling has resulted in spotty data. However, the distribution does not show significant change with time.

WATER QUALITY AS AFFECTED BY RECHARGE

The major groundwater quality feature of the Bird's Nest Aquifer is the poor water quality zone in the NE area. The uninhabited and unutilized nature of the region makes human-originated pollution unlikely. The fact that the ions which are characteristic of the aquifer material itself (sodium and bicarbonate) are widely distributed, while the ions characteristic of Evacuation

Creek waters (calcium, magnesium, and sulfate) are concentrated in the high TDS zone, indicates that Evacuation Creek recharge is the source of the high TDS water. The TDS of the aquifer water is somewhat higher than the water of Evacuation Creek, and the difference is mainly in sodium and bicarbonate. This increase would be expected if the recharge water dissolved some nahcolite as it moved through the aquifer.

Two facts are not explained by the recharge from Evacuation Creek indicated by water quality and temperature considerations. They are the source of the better quality water in the Bird's Nest Aquifer beneath Tract U-a and the improvement in water quality along the course of Evacuation Creek (Figure 6-25; see Section 5). There is no plausible mechanism for the removal of such soluble and mobile ions as sodium and sulfate from either the creek or the aquifer. A more likely mechanism is dilution.

Five possible sources of the relatively good quality water beneath Tract U-a exist:

1. Upward leakage through the Mahogany Zone from the Douglas Creek or Caver Aquifers
2. Downward leakage from the White River
3. Downward leakage from precipitation
4. Recharge from alluvium of Asphalt Wash
5. Downgradient recharge from Bird's Nest Aquifer above Evacuation Creek.

The first possibility seems unlikely due to the low permeability of the Mahogany Zone, but such leakage has been reported in the Piceance Basin. An argument from groundwater temperature has already been presented for the second possibility. Downward leakage from precipitation is not likely because of the low precipitation and high evaporation of the region, but it is not impossible. The curve of the 1,478-meter (4,850-foot) equipotential line in Figure 6-5 would support the fourth possibility. Unfortunately, no water quality analyses from the alluvium of Asphalt Wash are available.

The fifth possibility seems unlikely, but it does have some support and could explain several problems. If there were a source of good-quality water in the Bird's Nest Aquifer upgradient from Evacuation Creek, just to the south of the Tract U-b boundary, with enough head to intercept the alluvium of the creek, the water would flow in two directions. Some would continue to flow downgradient, mixing with some Evacuation Creek water, to contribute at least part of the lower TDS water beneath Tract U-a. The rest of the water would flow down Evacuation Creek through the alluvium, mixing with the high TDS Evacuation Creek water as it flowed. Such an exchange of aquifer and creek water would explain the improvement of the Evacuation Creek water without any increase in discharge. In Figure 6-1 the position of well P-3 is near the sodium bicarbonate end of the SW Bird's Nest Aquifer field. If water of such quality were mixing with Evacuation Creek water in the creek bed alluvium, analyses of wells penetrating the creek alluvium and the aquifer beneath the alluvium should fall between the Evacuation Creek and the SW Bird's Nest Aquifer fields. In fact, this is where these analyses do plot. The underlined points in Figure 6-2 are wells along Evacuation Creek.

The presence of water from another source than Evacuation Creek in the Bird's Nest Aquifer above the creek would also explain the curve of the equipotential lines above the creek in Figure 6-5. Possible sources for such water would be downward leakage of precipitation or recharge by precipitation at the outcrop of the Bird's Nest Aquifer on the wall of Hell's Hole Canyon, or upward leakage from the Douglas Creek or deeper aquifers.

Thus such a recharge of the aquifer would explain the source of the good-quality water moving past well P-3, the cause of the improvement of water quality in Evacuation Creek without increased discharge, the quality of water in wells along Evacuation Creek, and the position of the equipotential lines in the Bird's Nest Aquifer above Evacuation Creek.

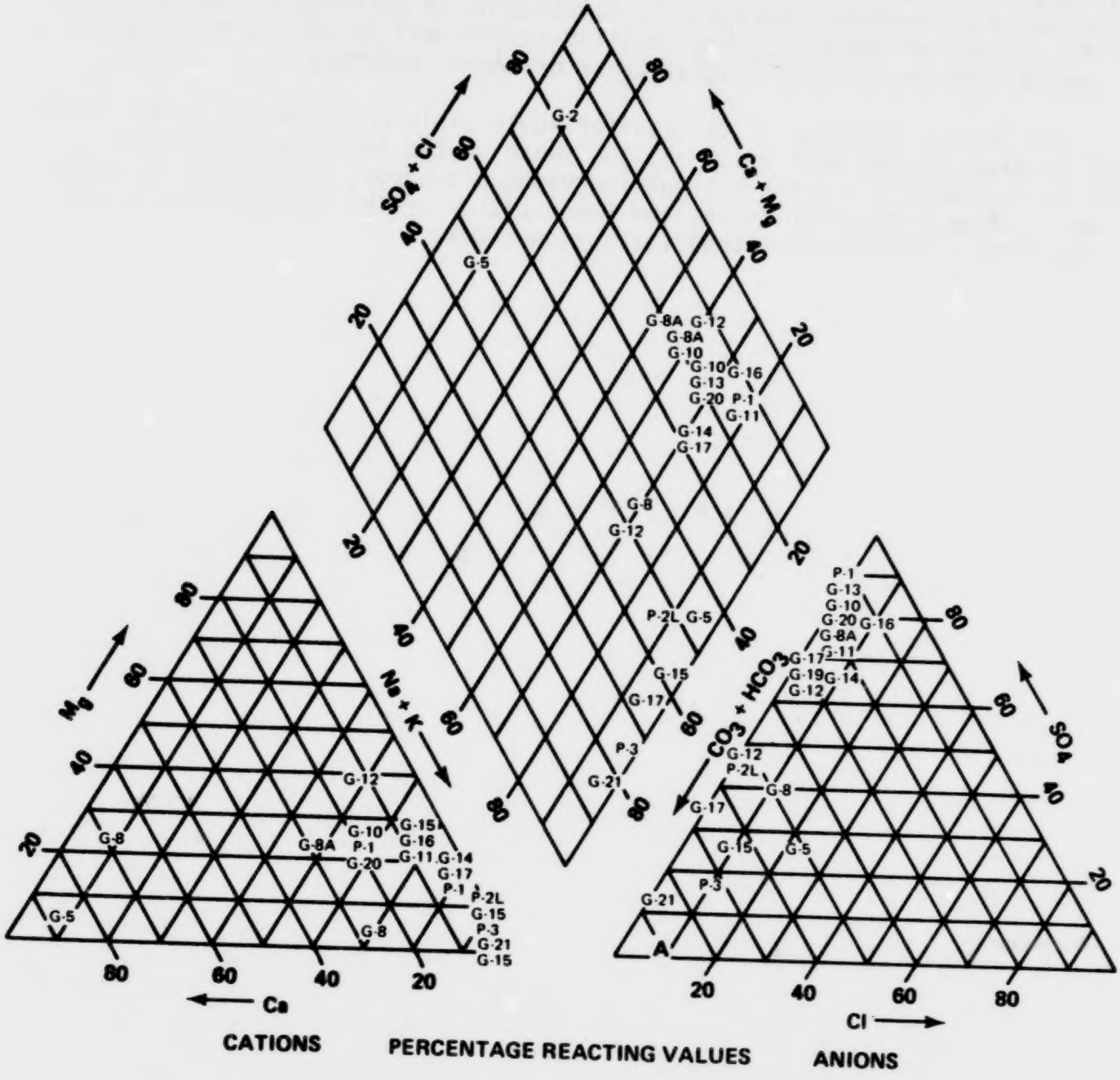


Figure 6-1. Water analysis diagram for Bird's Nest Aquifer.

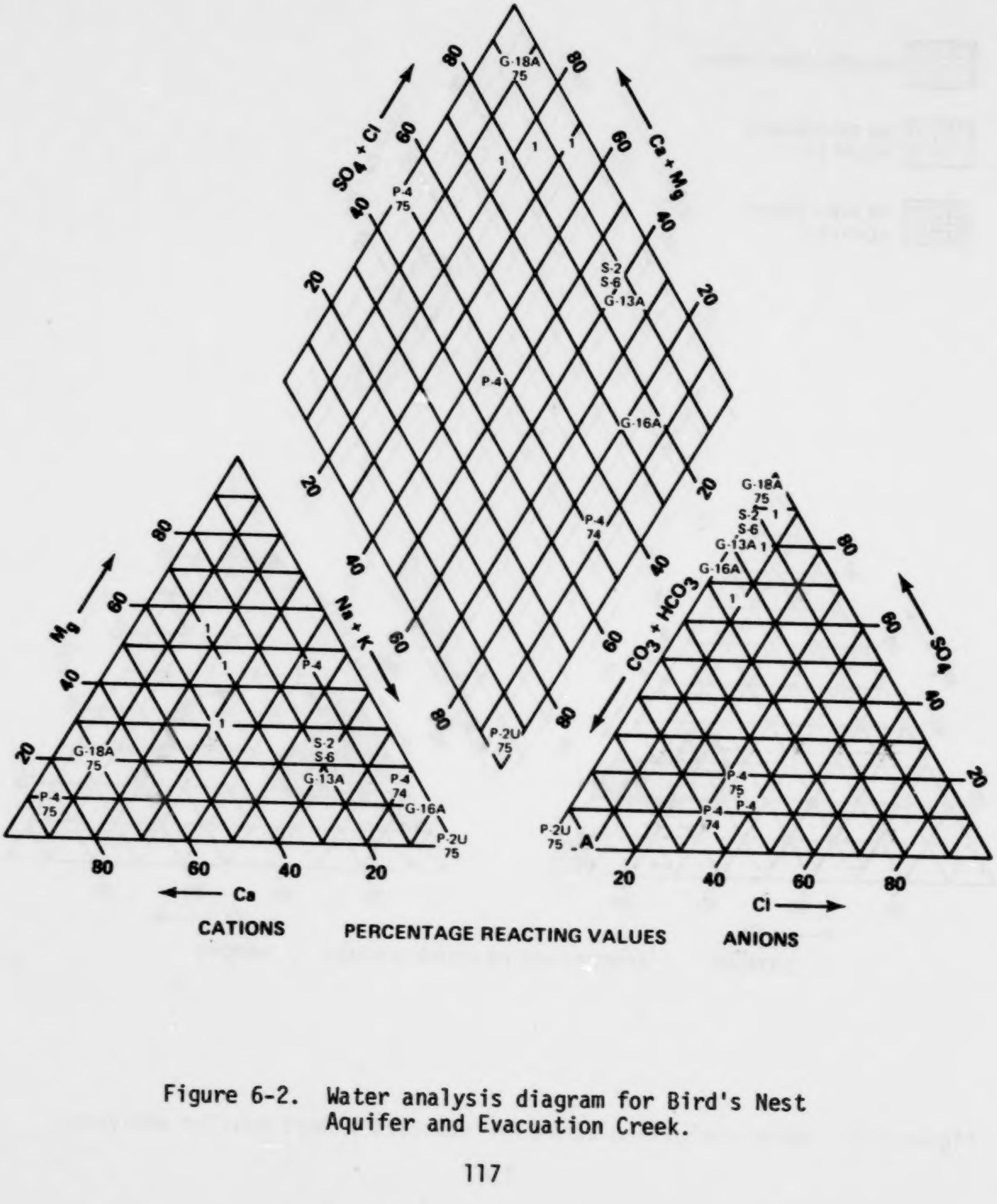


Figure 6-2. Water analysis diagram for Bird's Nest Aquifer and Evacuation Creek.

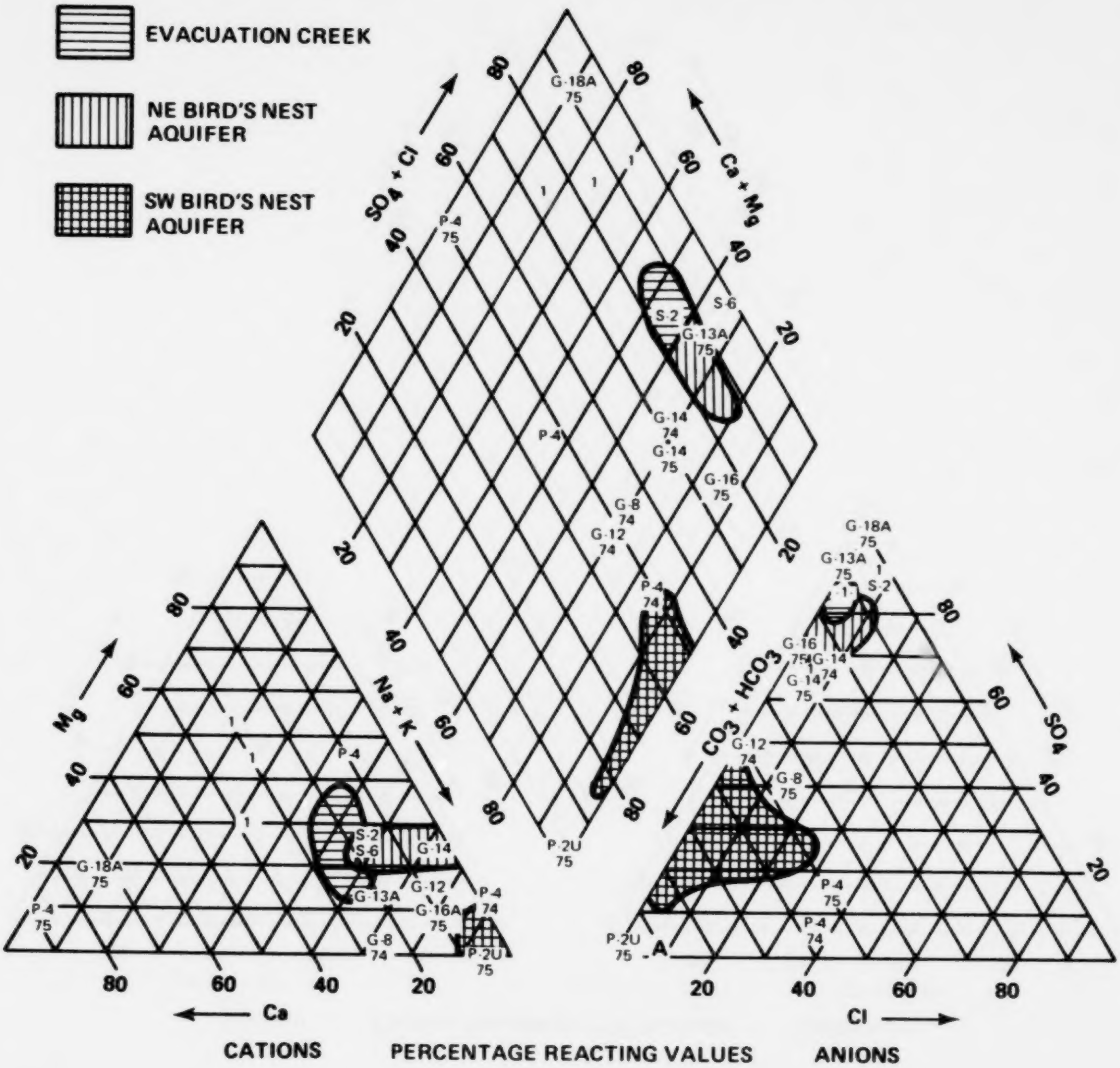


Figure 6-3. Water analysis diagram for non-Bird's Nest Aquifer analyses.

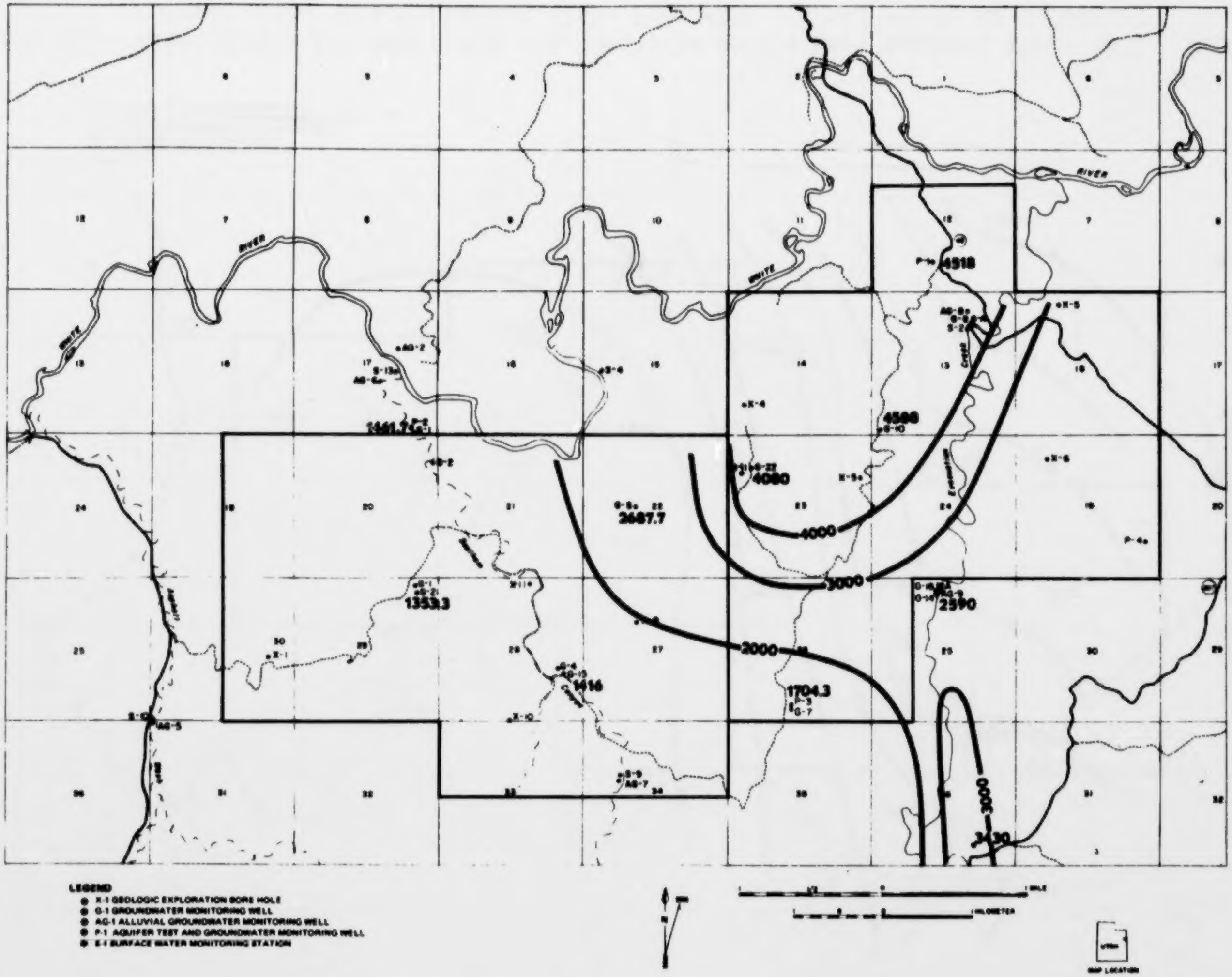

LEGEND
● X-1 GEOLOGIC EXPLORATION BORE HOLE
● G-1 GROUNDWATER MONITORING WELL
● AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
● P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
● S-1 SURFACE WATER MONITORING STATION
WHITE RIVER
4000
3000
2000
3000
4518
4588
4080
2687.7
1353.3
1416
1704.3
2390
3430
1461.7
1 MILE
1 KILOMETER
UTAH
MAP LOCATION

Figure 6-4. Mean total dissolved solids (TDS) concentrations (mg/l) in the Bird's Nest Aquifer (data from WRSP, 1976b; map by GE—TEMPO).

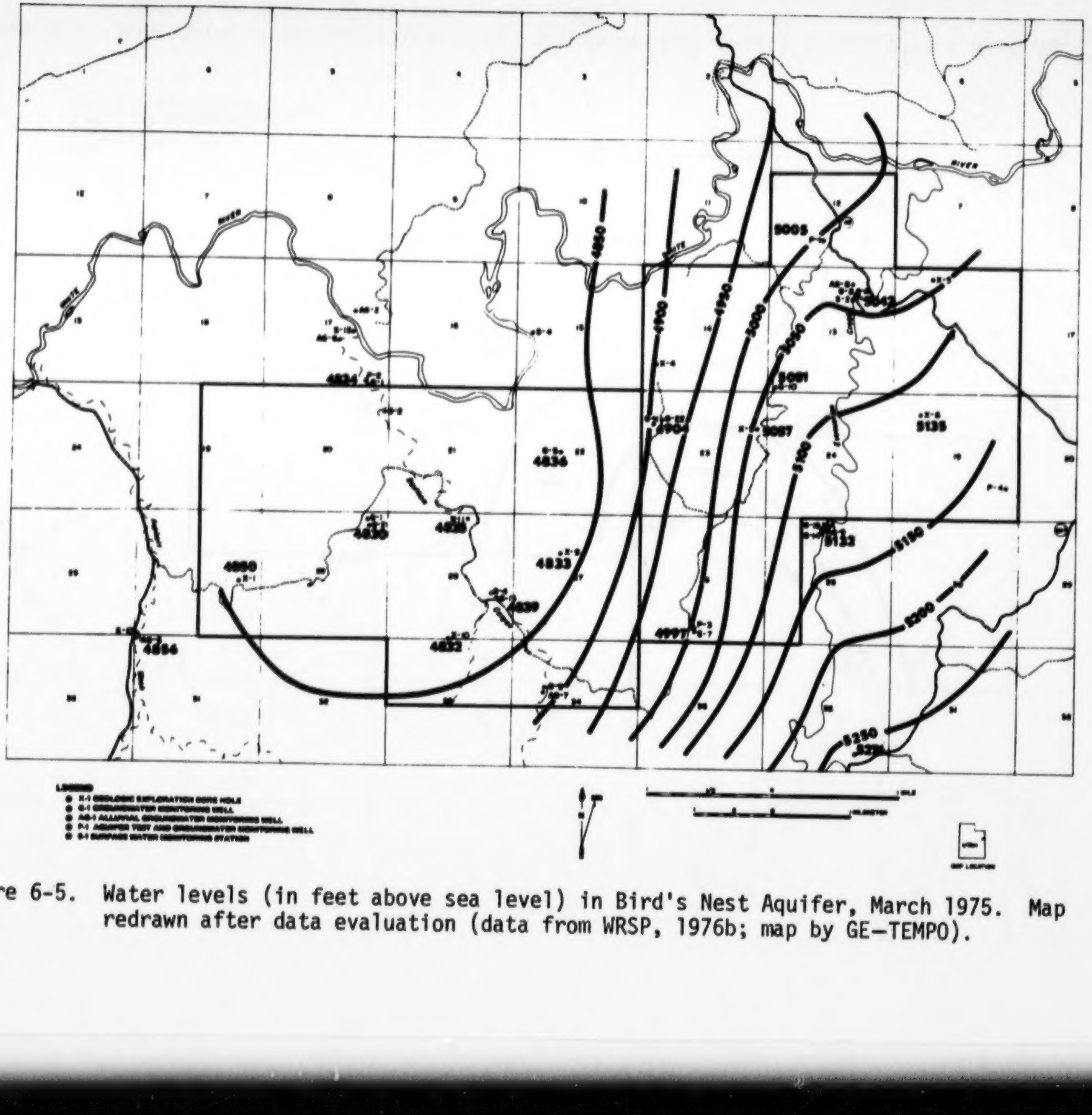

RIVER
WHITE
4850
4900
4950
5000
5050
5100
5150
5200
5250
5005
5043
5081
5087
5135
5132
4904
4997
4836
4833
4839
4832
4838
4830
4850
4834
4856

Figure 6-5. Water levels (in feet above sea level) in Bird's Nest Aquifer, March 1975. Map redrawn after data evaluation (data from WRSP, 1976b; map by GE—TEMPO).

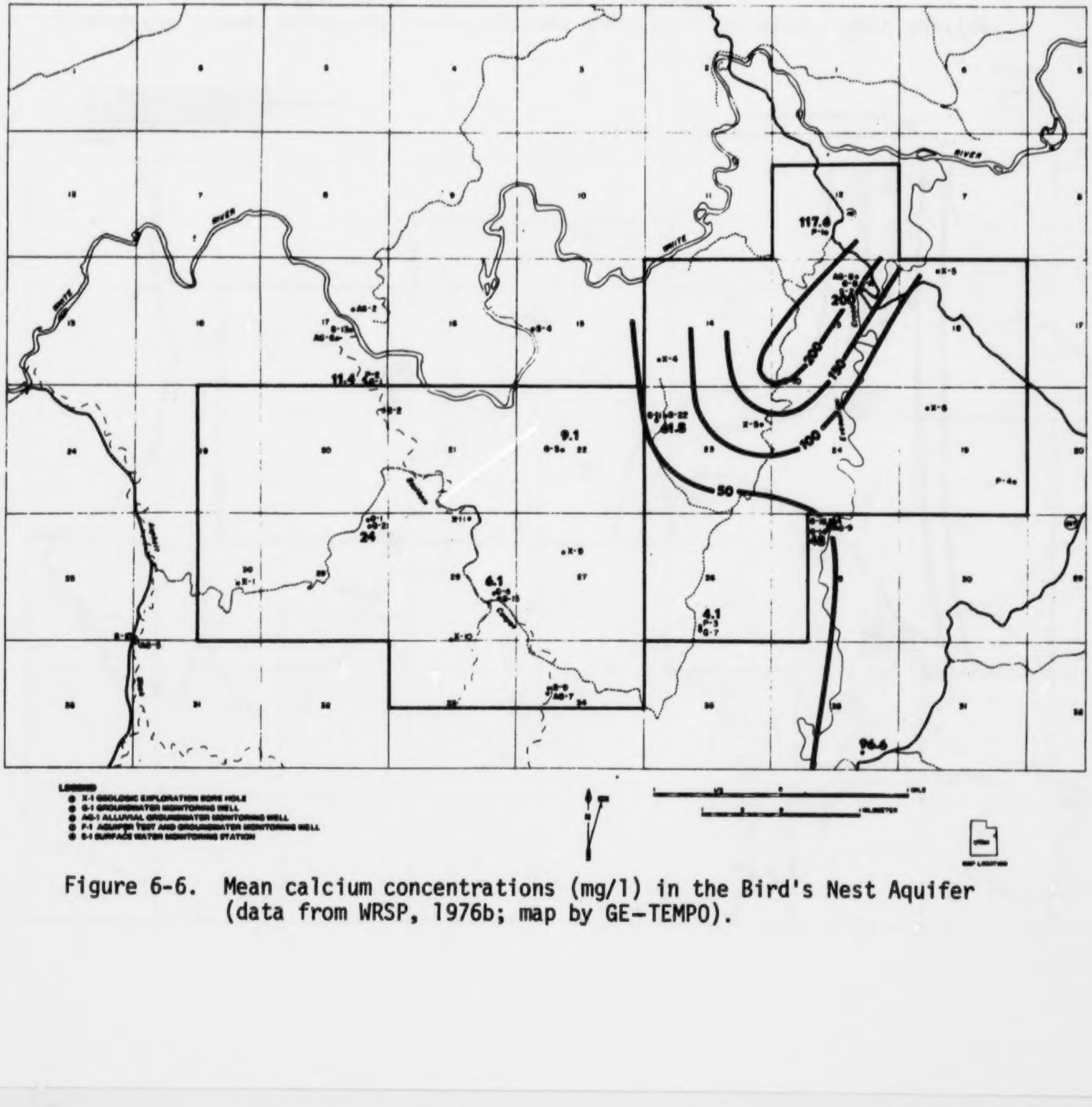

117.6
200
150
100
50
61.8
9.1
11.4
24
6.1
4.1
46
96.6
WHITE RIVER
LEGEND
X-1 GEOLOGIC EXPLORATION CORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
MAP LOCATION

Figure 6-6. Mean calcium concentrations (mg/l) in the Bird's Nest Aquifer (data from WRSP, 1976b; map by GE-TEMPO).

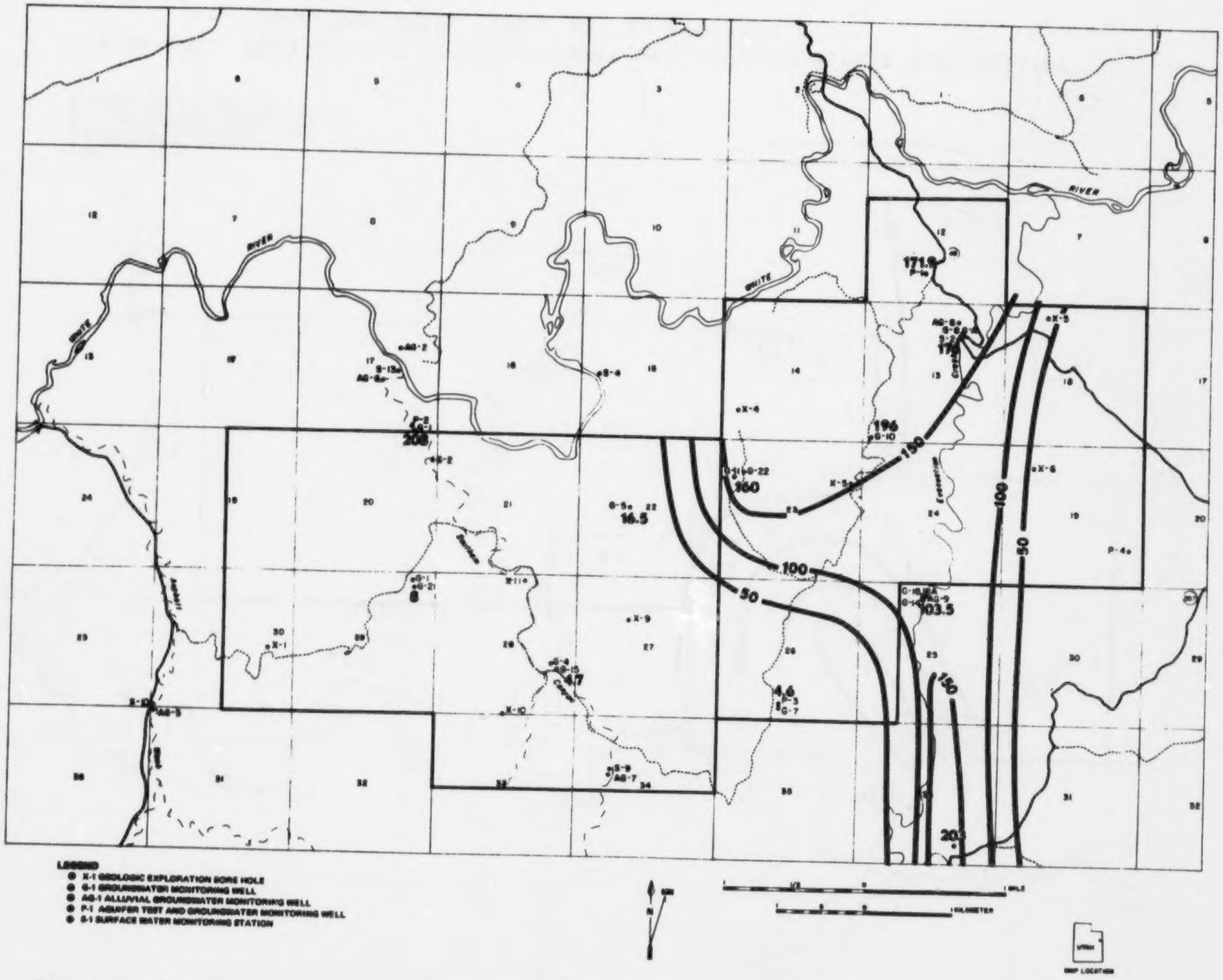

LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
WHITE RIVER
50
100
150
200
171.9
176
196
160
16.5
208
8
4.7
4.6
103.5
MILE
KILOMETER
N
UTAH
MAP LOCATION

Figure 6-7. Mean magnesium concentrations (mg/l) in the Bird's Nest Aquifer (data from WRSP, 1976b; map by GE—TEMPO).

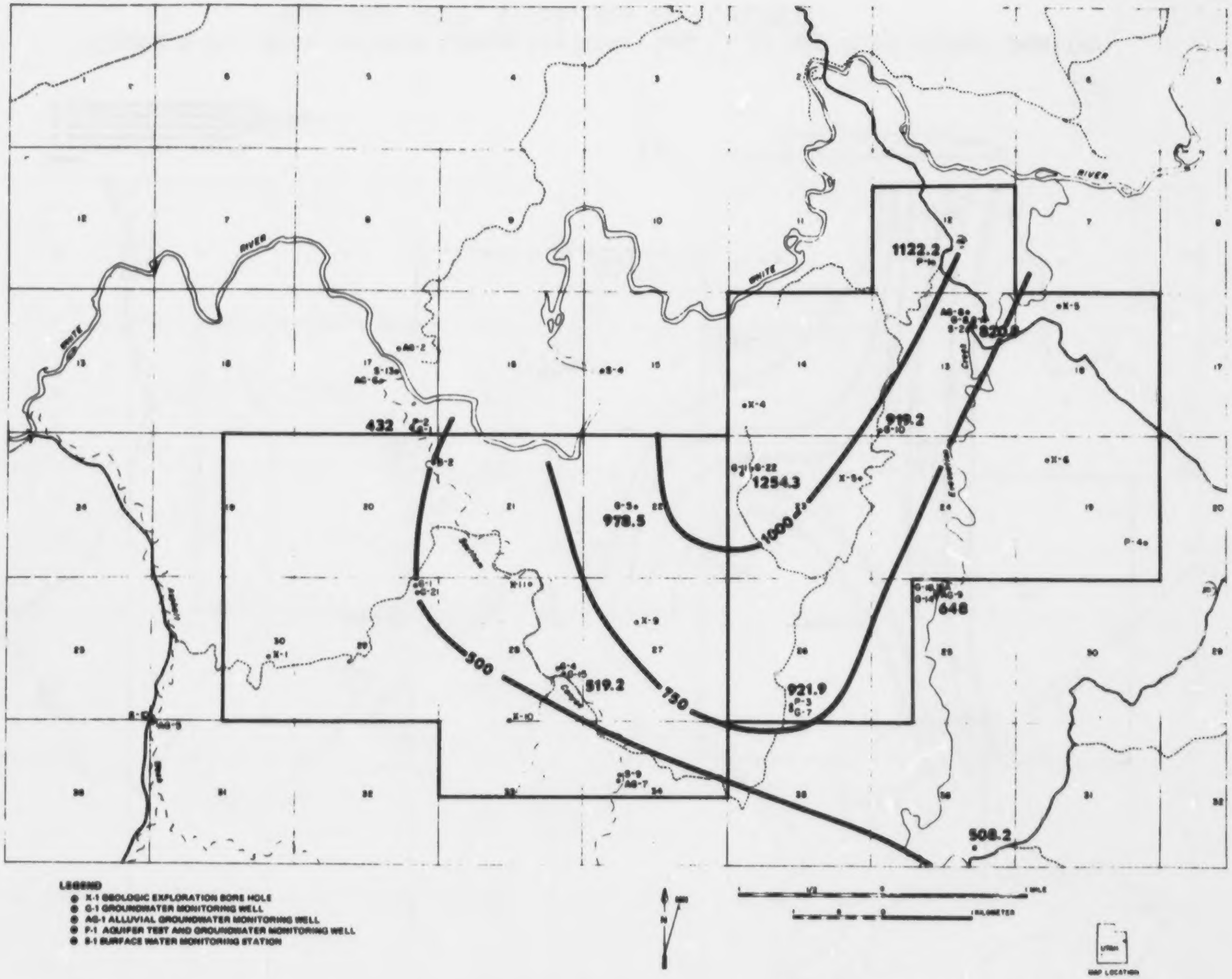

1122.2
P-1
820.8
AG-8
S-2
X-5
14
13
18
17
X-4
919.2
G-10
X-6
G-22
1254.3
X-9
1000
24
19
20
P-4
648
AG-9
G-14
25
30
29
921.9
P-3
G-7
22
978.5
G-5
21
20
19
13
24
25
36
12
7
8
9
10
11
1
2
3
4
5
6
15
16
17
X-8
750
X-11
AG-1
AG-21
X-1
500
819.2
X-10
G-9
AG-7
33
34
35
36
31
32
508.2
432
G-2
AG-2
S-13
AG-6
S-4
WHITE
RIVER
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
1 MILE
KILOMETER
MAP LOCATION
UTAH

Figure 6-8. Mean sodium plus potassium concentrations (mg/l) in the Bird's Nest Aquifer (data from WRSP, 1976b; map by GE—TEMPO).

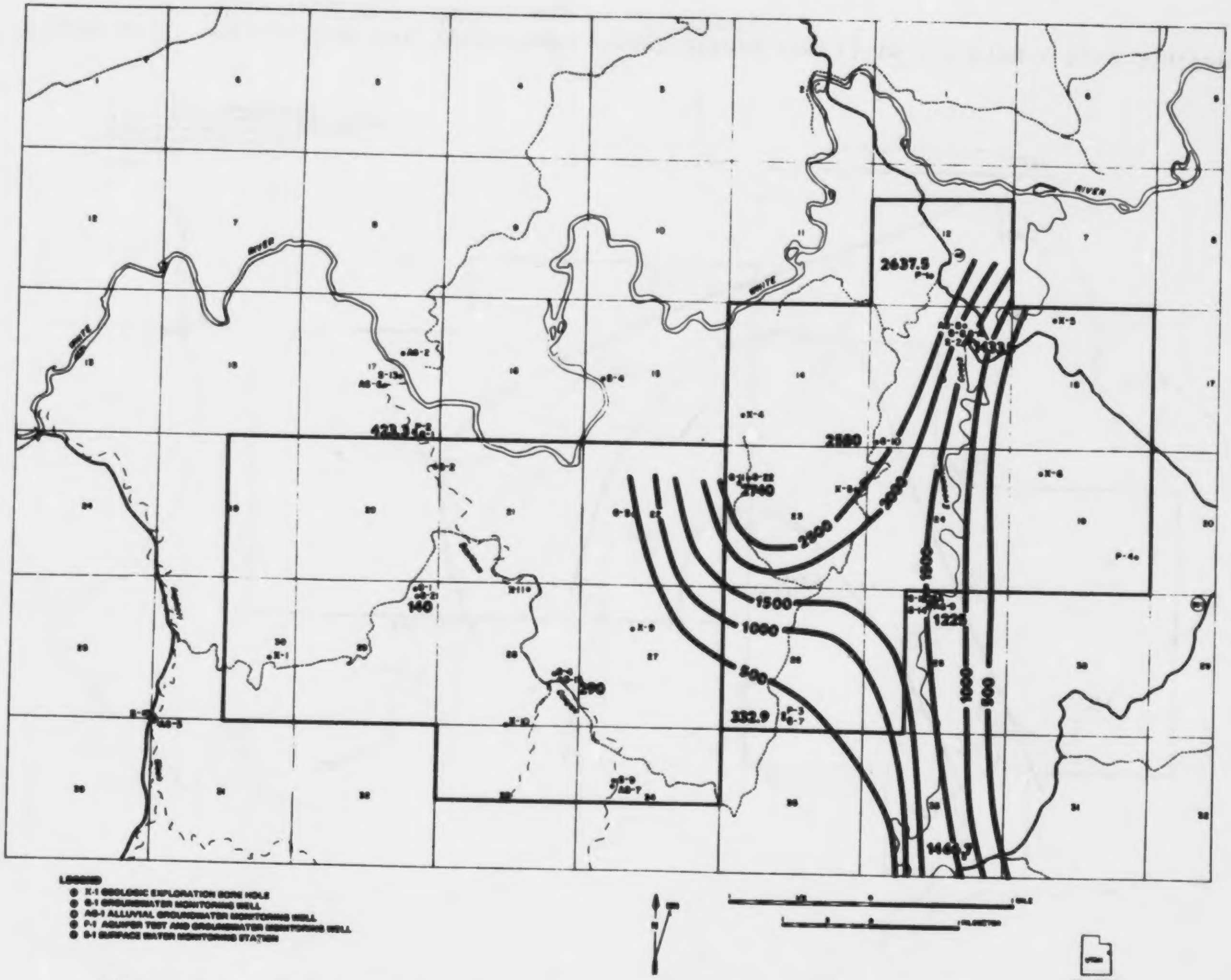

WHITE RIVER
2637.5
2180
2740
1225
332.9
290
140
423.1
500
1000
1500
2000
2500
LEGEND
X-1 GEOLOGIC EXPLORATION CORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
MAP LOCATION

Figure 6-9. Mean sulfate concentrations (mg/l) in the Bird's Nest Aquifer (data from WRSP, 1976b; map by GE—TEMPO).

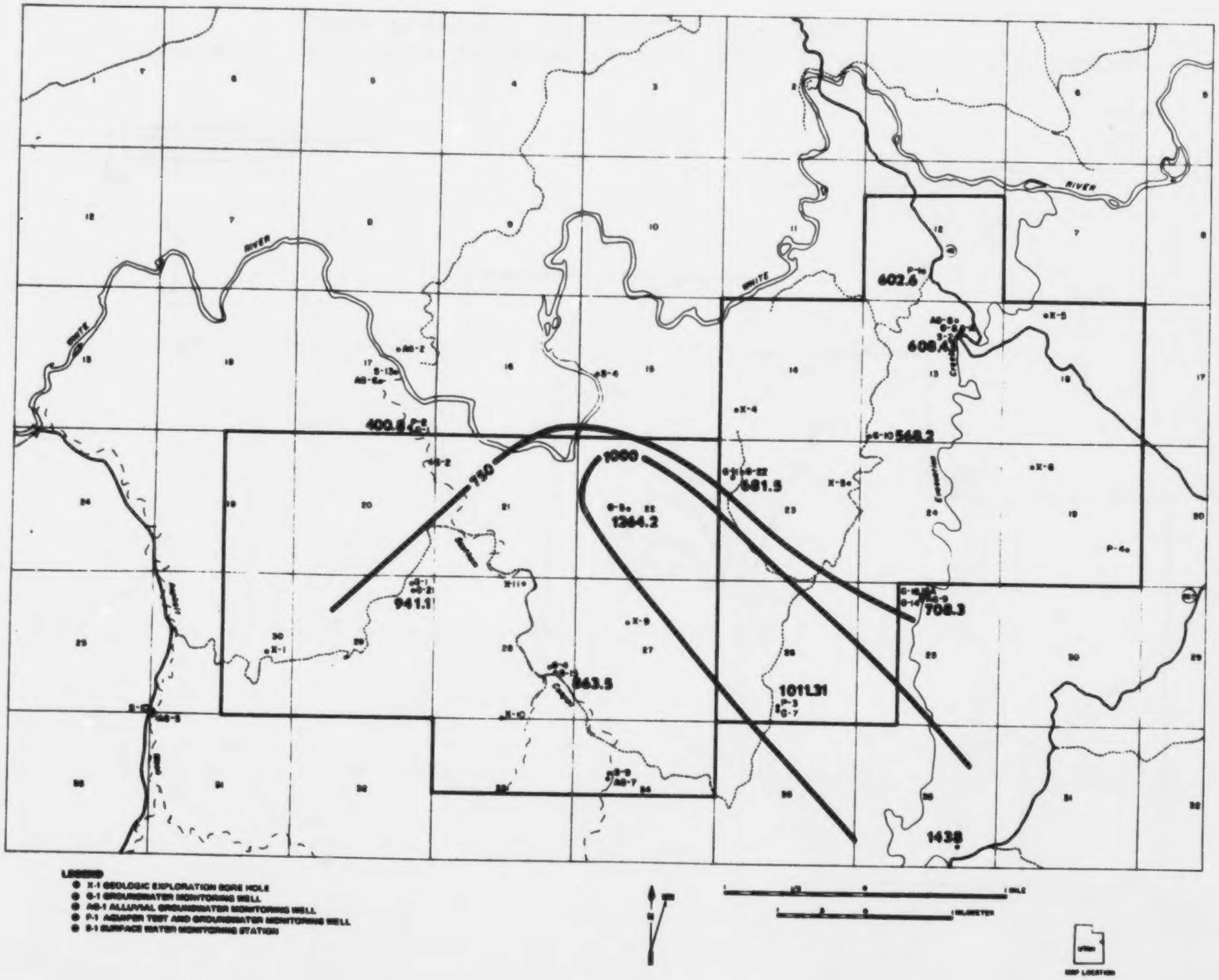

WHITE RIVER
750
1000
602.6
608.4
568.2
681.5
1364.2
400.6
941.1
863.5
1011.31
708.3
1438
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
MAP LOCATION

Figure 6-10. Mean carbonate and bicarbonate concentrations (mg/l) in the Bird's Nest Aquifer (data from WRSP, 1976b; map by GE—TEMPO).

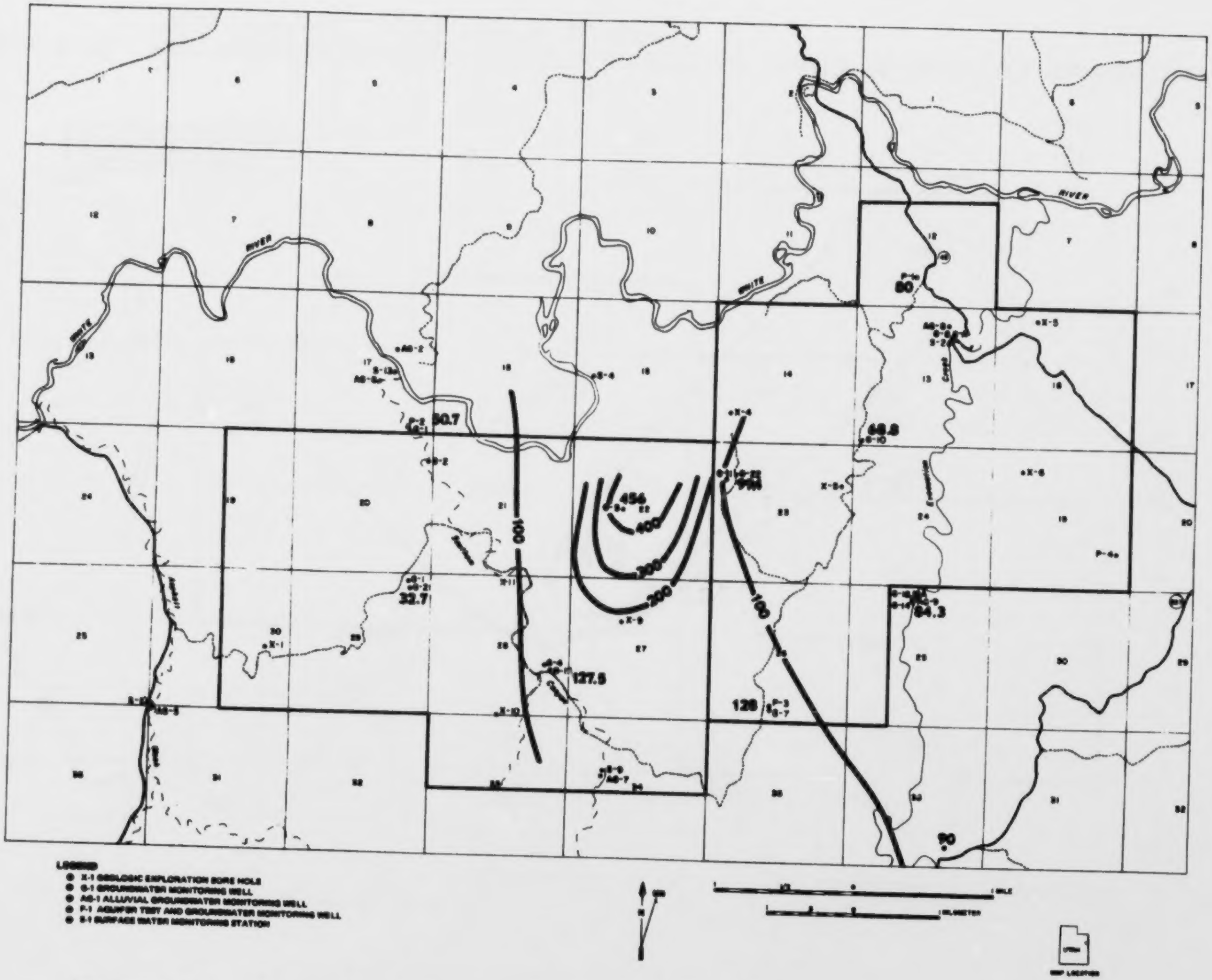

WHITE RIVER
100
454
400
300
200
100
30.7
32.7
127.5
128
68.8
64.3
80
90
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
MAP LOCATION

Figure 6-11. Mean chloride concentrations (mg/l) in the Bird's Nest Aquifer (data from WRSP, 1976b; map by GE—TEMPO).

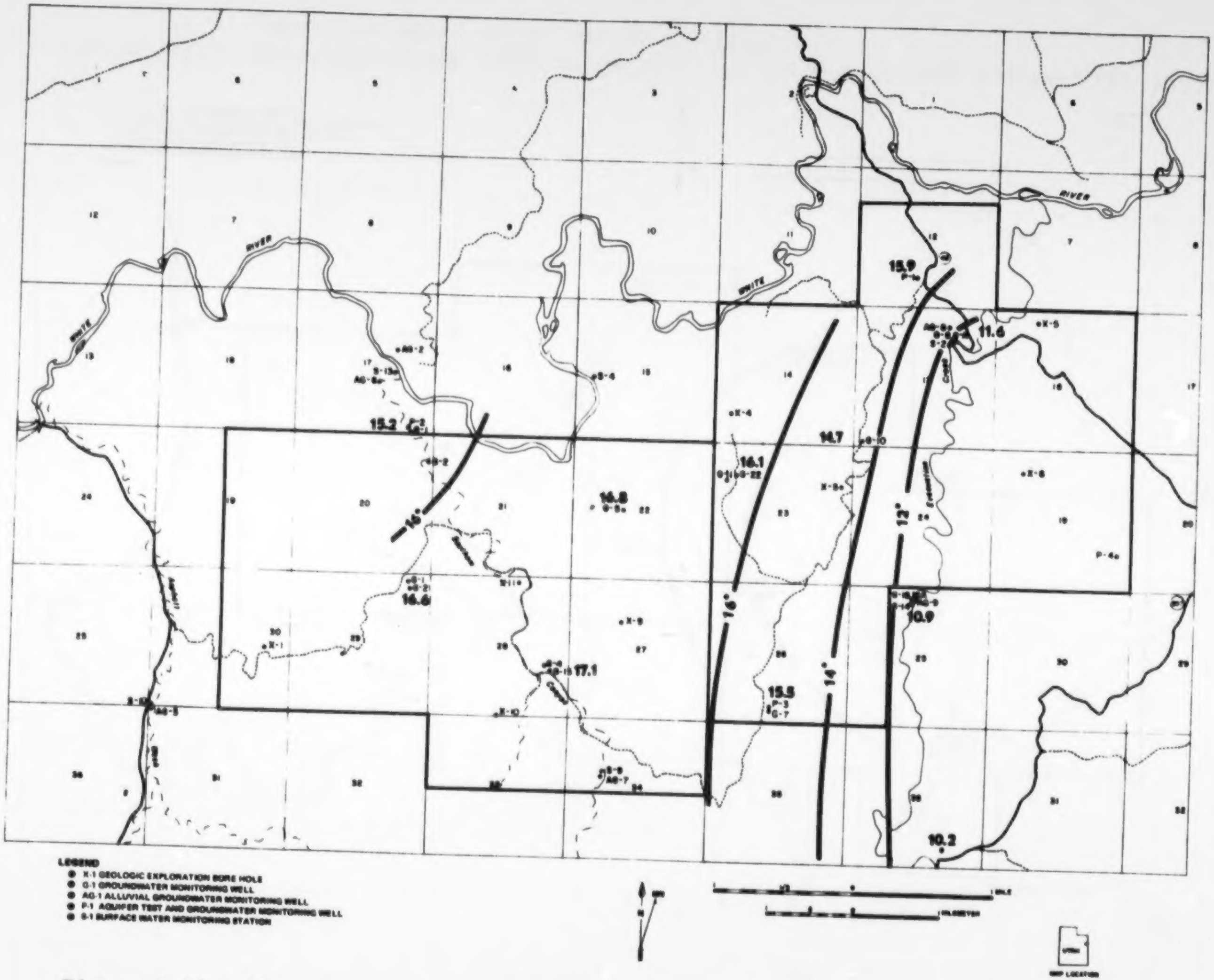

WHITE RIVER
RIVER
15.9
11.6
14.7
16.1
16.8
15.2
16.6
17.1
15.5
10.9
10.2
16°
14°
12°
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
UTAH
MAP LOCATION

Figure 6-12. Mean temperature (degrees Celsius) in the Bird's Nest Aquifer (data from WRSP, 1976b; map by GE-TEMPO).

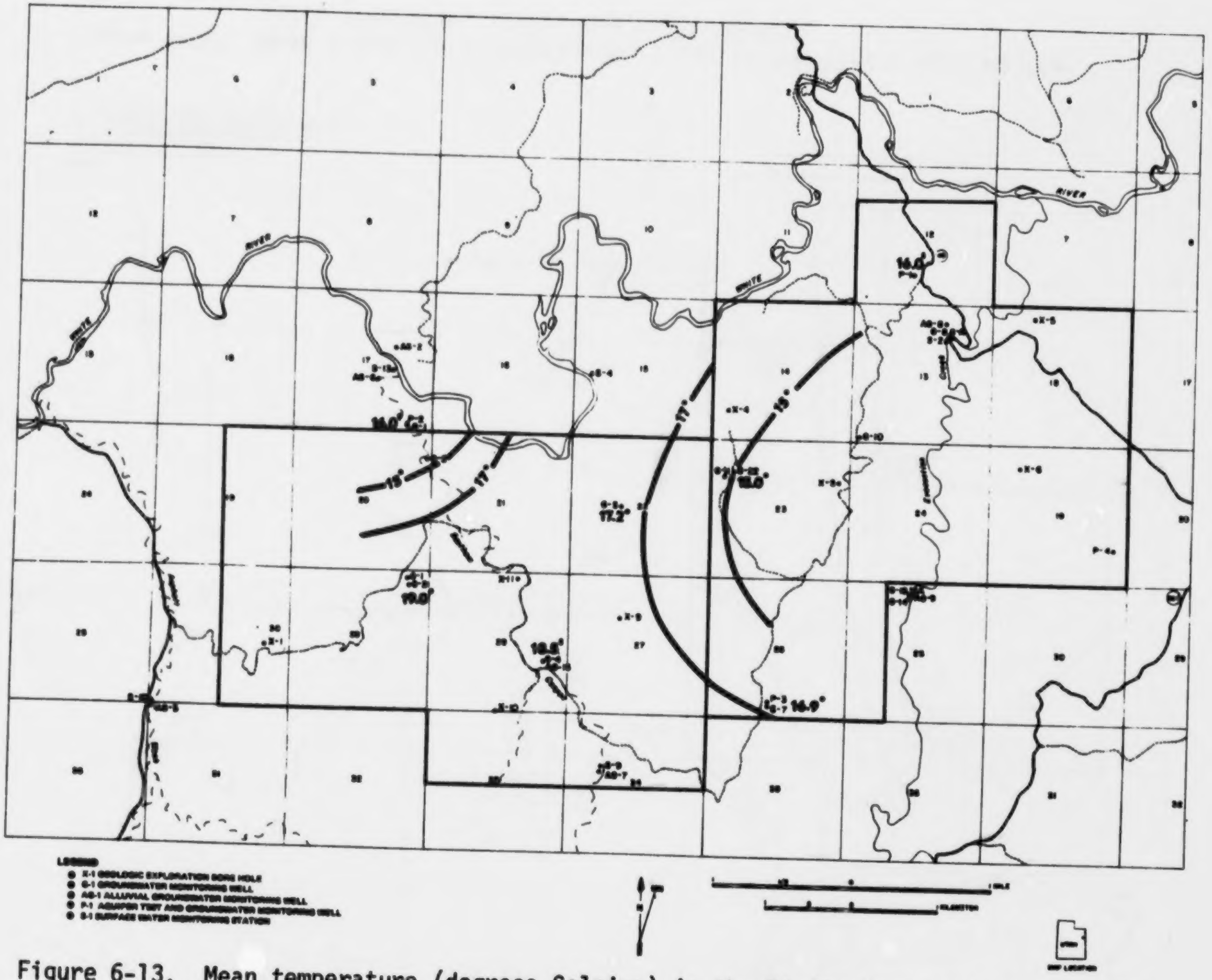

WHITE RIVER
15°
17°
16.0°
18.0°
17.2°
19.0°
18.6°
16.9°
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION

Figure 6-13. Mean temperature (degrees Celsius) in the Bird's Nest Aquifer, May 1974 (data from WRSP, 1976b; map by GE—TEMPO).

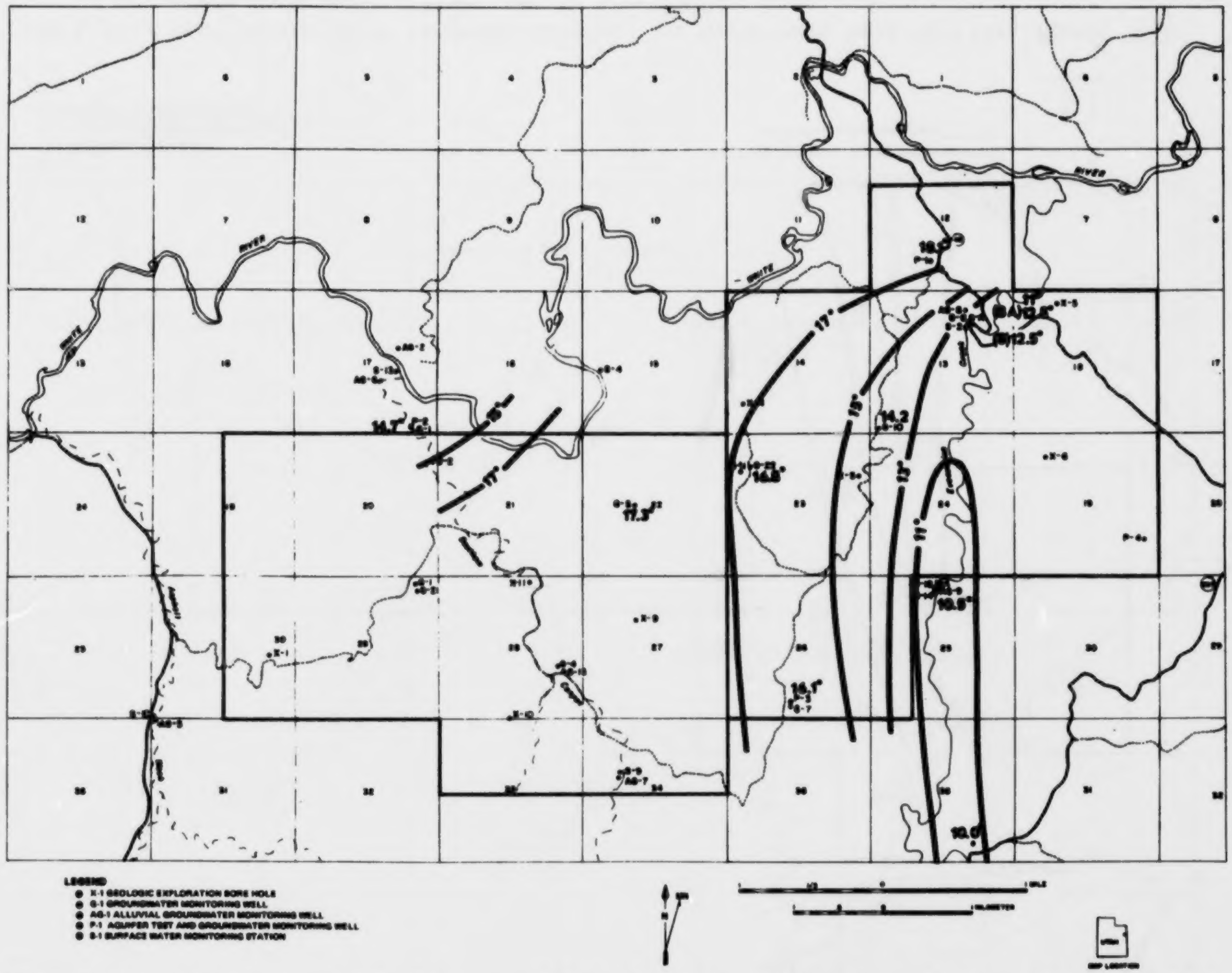

LEGEND
● X-1 GEOLOGIC EXPLORATION BORE HOLE
● G-1 GROUNDWATER MONITORING WELL
● AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
● P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
● S-1 SURFACE WATER MONITORING STATION
WHITE RIVER
17°
15°
13°
11°
14.7°
17.3°
14.2
16.1°
10.5°
12.5°
10.0°

Figure 6-14. Mean temperature (degrees Celcius) in the Bird's Nest Aquifer, November 1974 (data from WRSP, 1976b; map by GE—TEMPO).

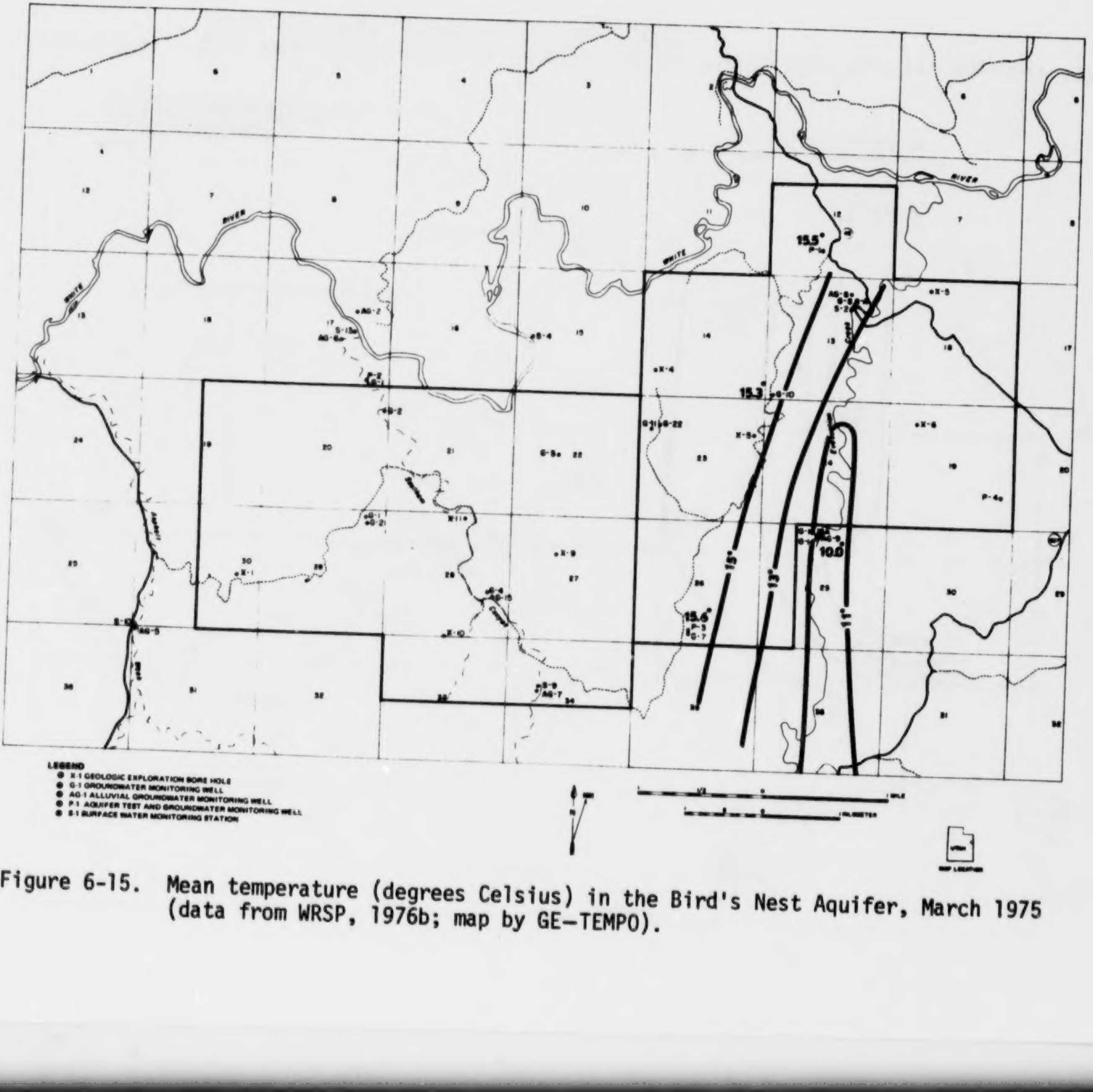

LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
WHITE
RIVER
15.5°
15.3°
15.6°
10.0
15°
13°
11°

Figure 6-15. Mean temperature (degrees Celsius) in the Bird's Nest Aquifer, March 1975 (data from WRSP, 1976b; map by GE—TEMPO).

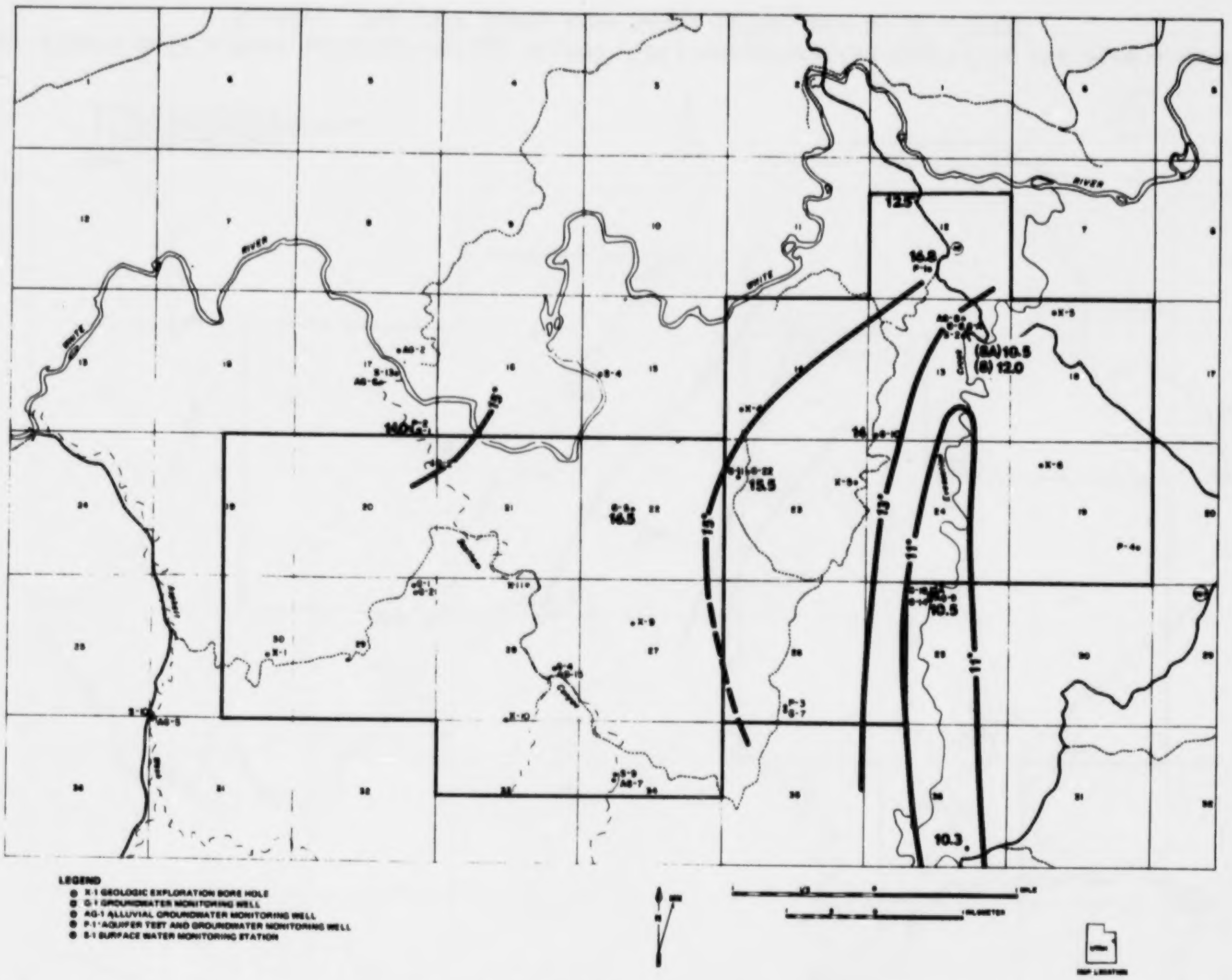

LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
WHITE RIVER
12.5°
16.5
(6A) 10.5
(6) 12.0
16
15.5
16.5
14.0
10.5
10.3
15°
13°
11°

Figure 6-16. Mean temperature (degrees Celsius) in the Bird's Nest Aquifer, November 1975 (data from WRSP, 1976b; map by GE-TEMPO).

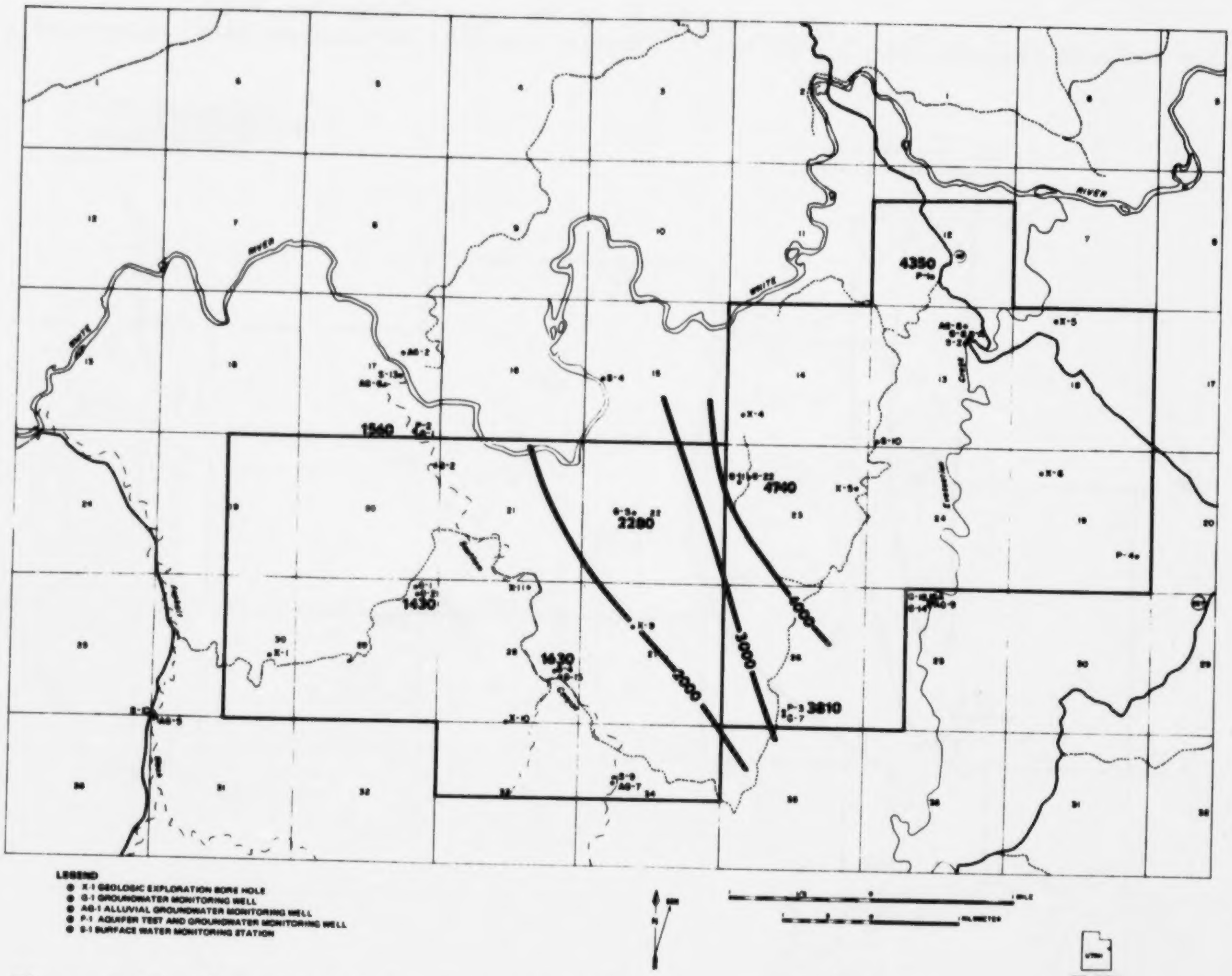

4350
4740
3810
2280
1540
1430
1630
4000
3000
2000
WHITE RIVER
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION

Figure 6-17. Mean total dissolved solids (TDS) concentration (mg/l) in the Bird's Nest Aquifer, May 1974 (data from WRSP, 1976b; map by GE—TEMPO).

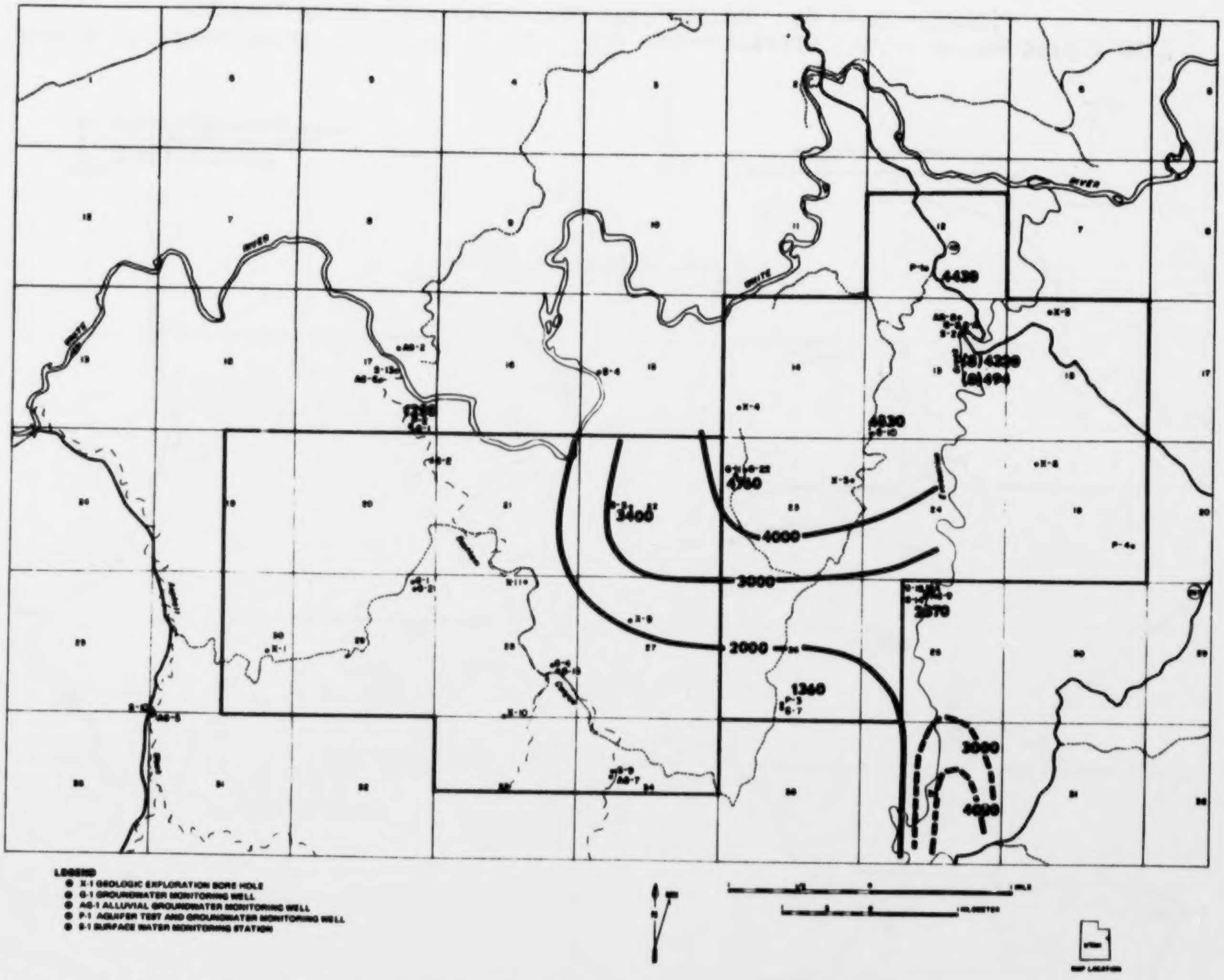

WHITE
WHITE
RIVER
4000
3000
2000
3000
4000
3400
4760
4830
4430
2870
1360
LEGEND
● X-1 GEOLOGIC EXPLORATION BORE HOLE
● G-1 GROUNDWATER MONITORING WELL
● AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
● P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
● S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
MAP LOCATION

Figure 6-18. Mean total dissolved solids (TDS) concentration (mg/l) in the Bird's Nest Aquifer, November 1974 (data from WRSP, 1976b; map by GE-TEMPO).

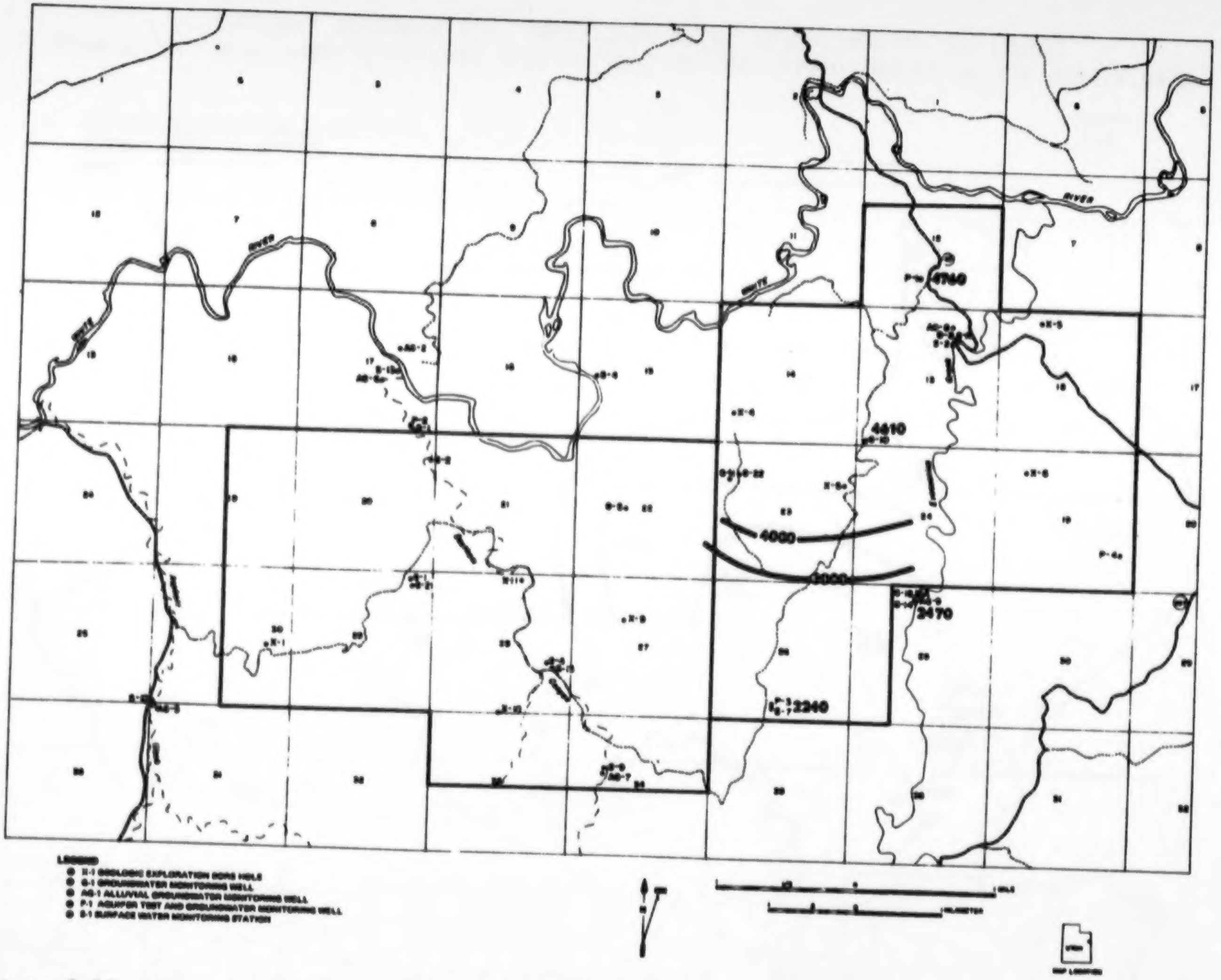

4760
4410
4000
3000
3470
2240
WHITE RIVER
LEGEND
X-1 GEOLOGIC EXPLORATION CORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION

Figure 6-19. Mean total dissolved solids (TDS) concentration (mg/l) in the Bird's Nest Aquifer, March 1975 (data from WRSP, 1976b; map by GE—TEMPO).

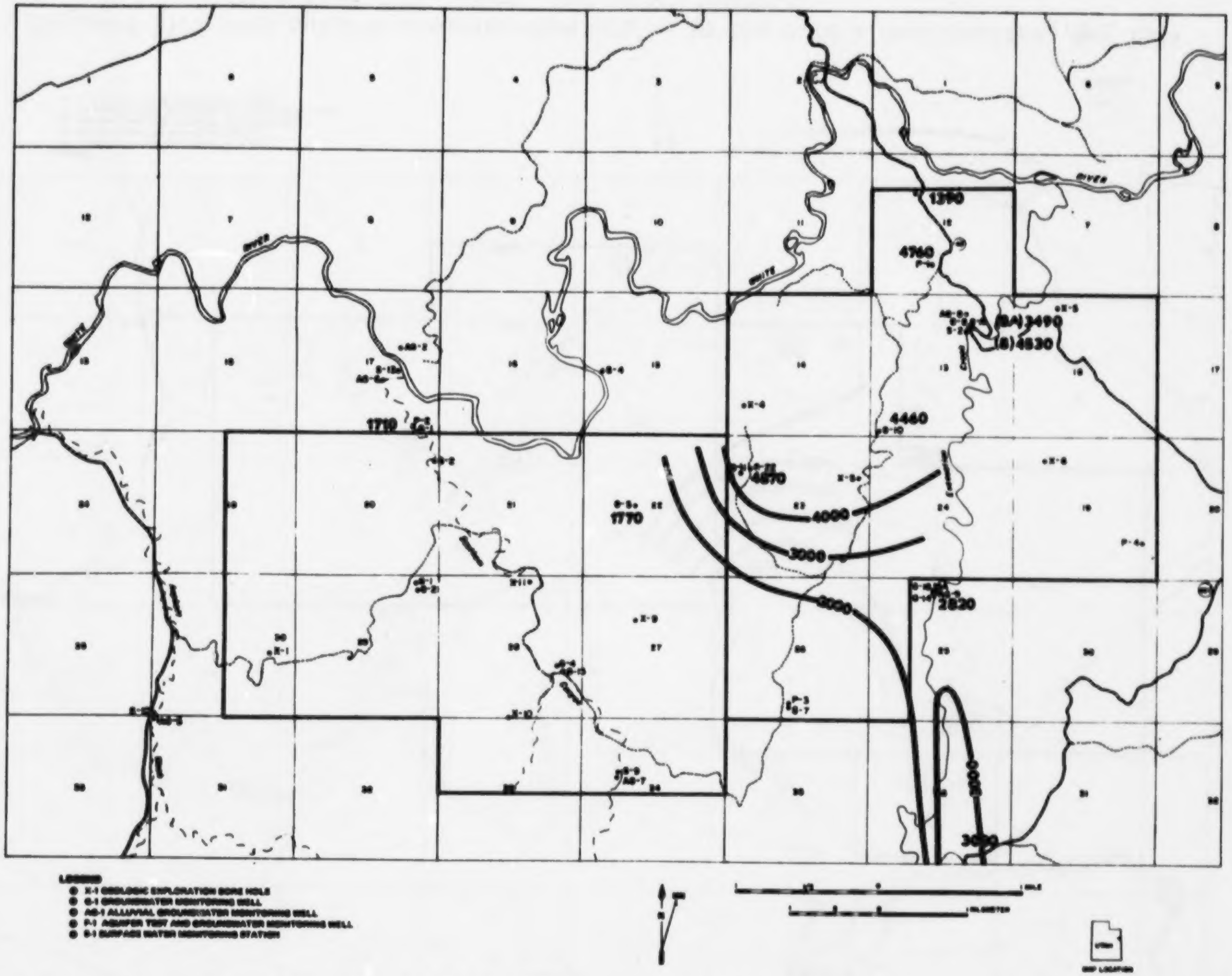

WHITE RIVER
1390
4760
(BA)3490
(B)4530
4460
4870
4000
3000
2000
1770
1710
2820
3000
LEGEND
X-1 GEOLOGIC EXPLORATION CORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION

Figure 6-20. Mean total dissolved solids (TDS) concentration (mg/1) in the Bird's Nest Aquifer, November 1975 (data from WRSP, 1976b; map by GE—TEMPO).

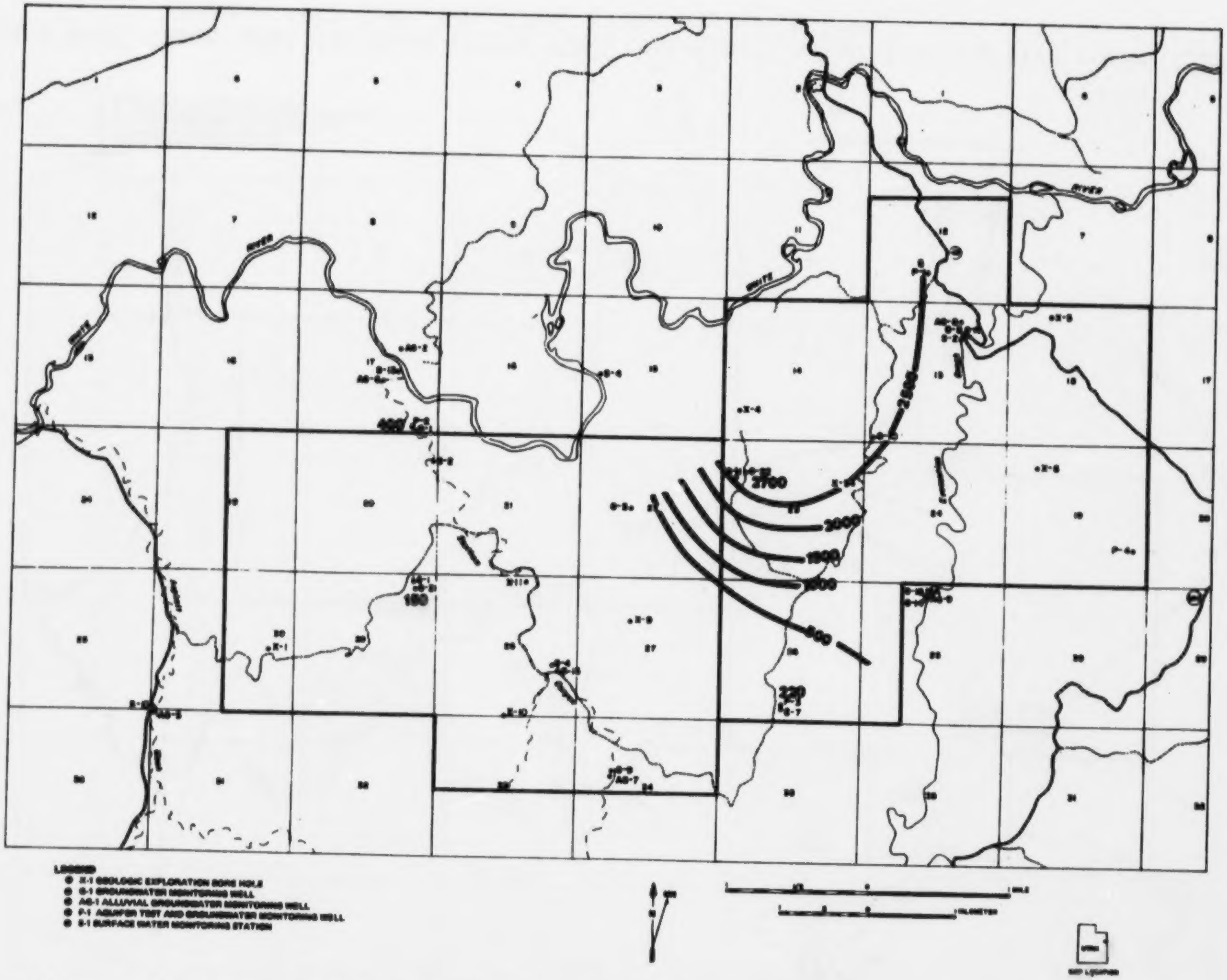

LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
2700
3000
2500
1500
1000
500
400
150
220
WHITE RIVER

Figure 6-21. Mean sulfate concentration (mg/l) in the Bird's Nest Aquifer, May 1974 (data from WRSP, 1976b; map by GE—TEMPO).

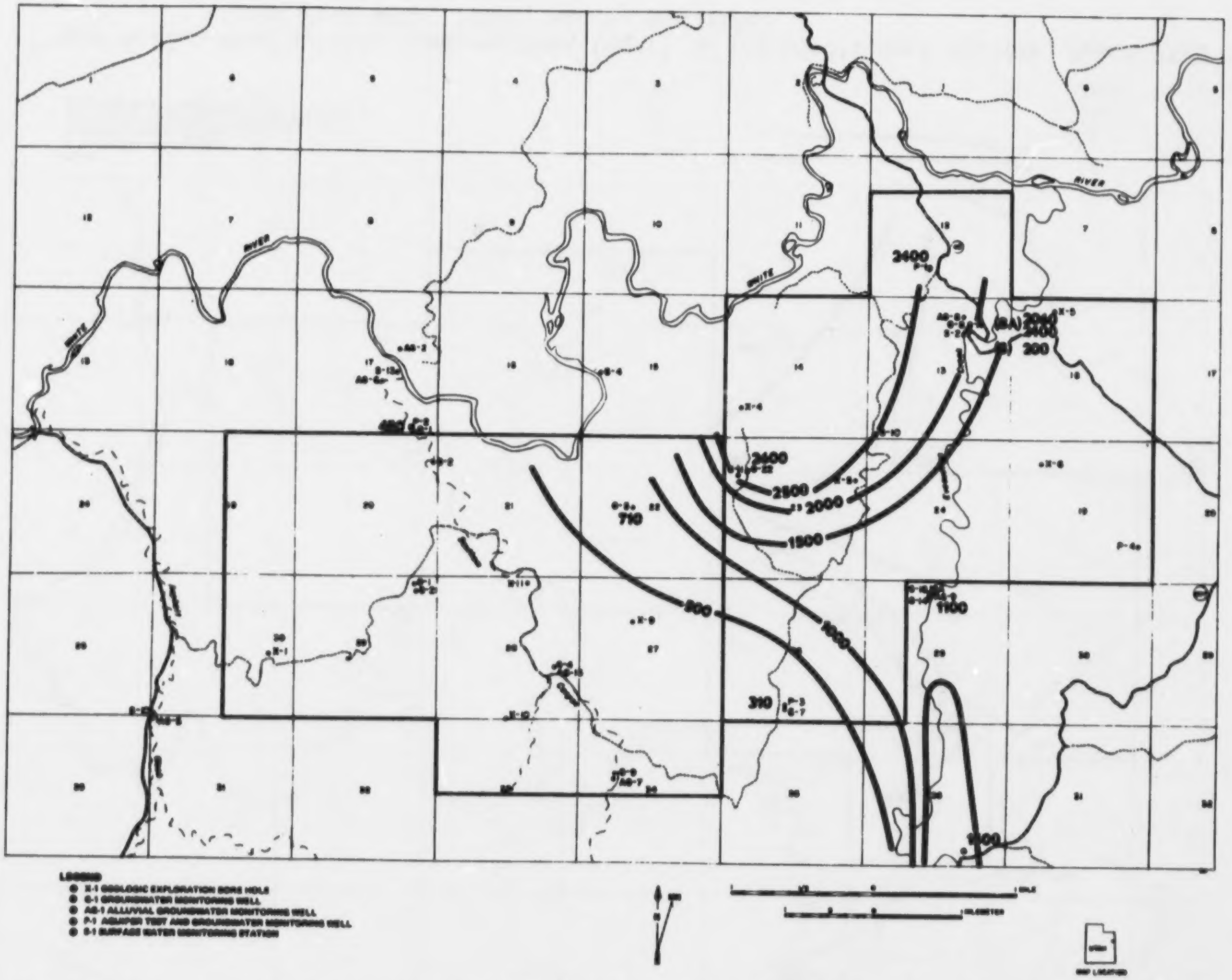
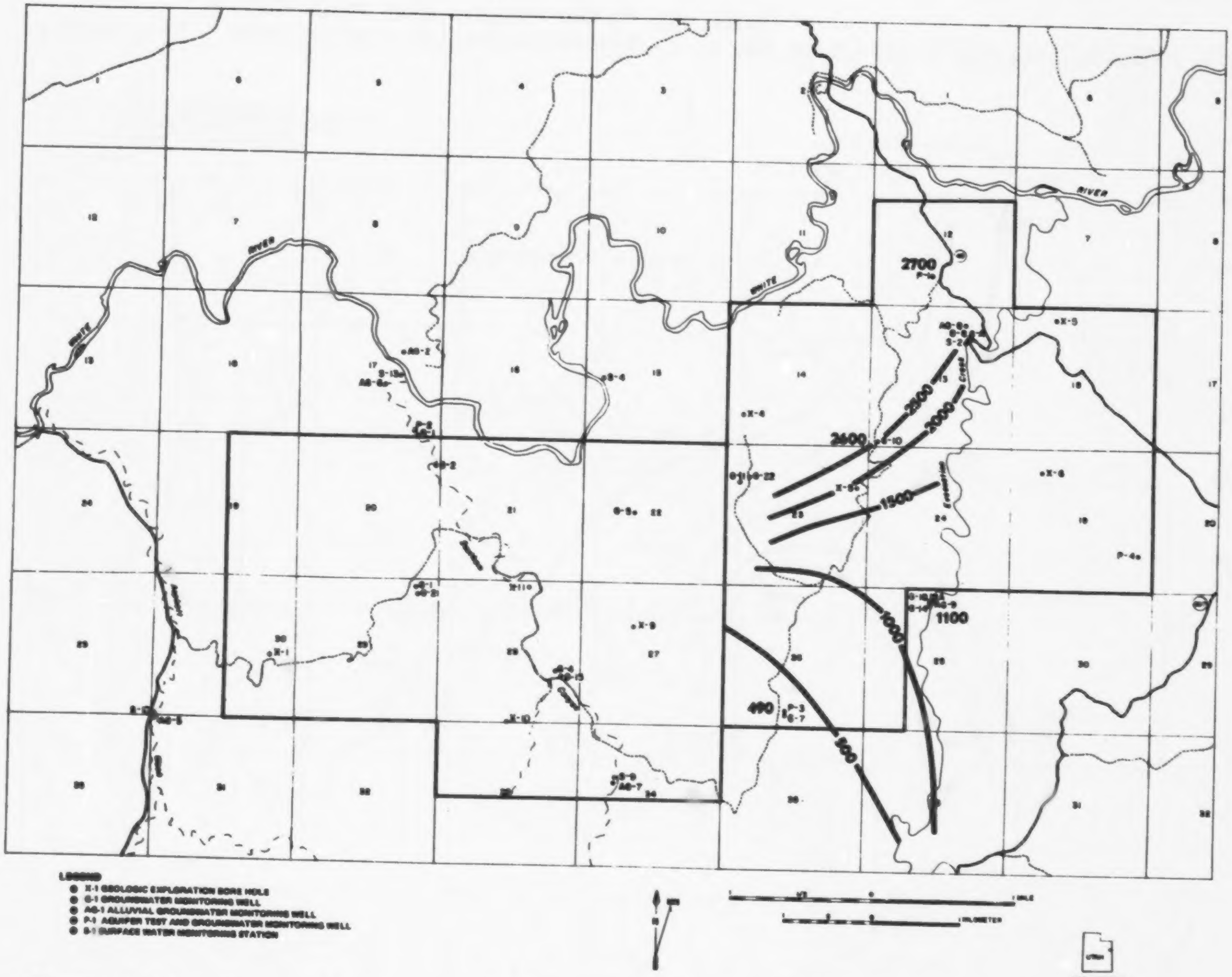
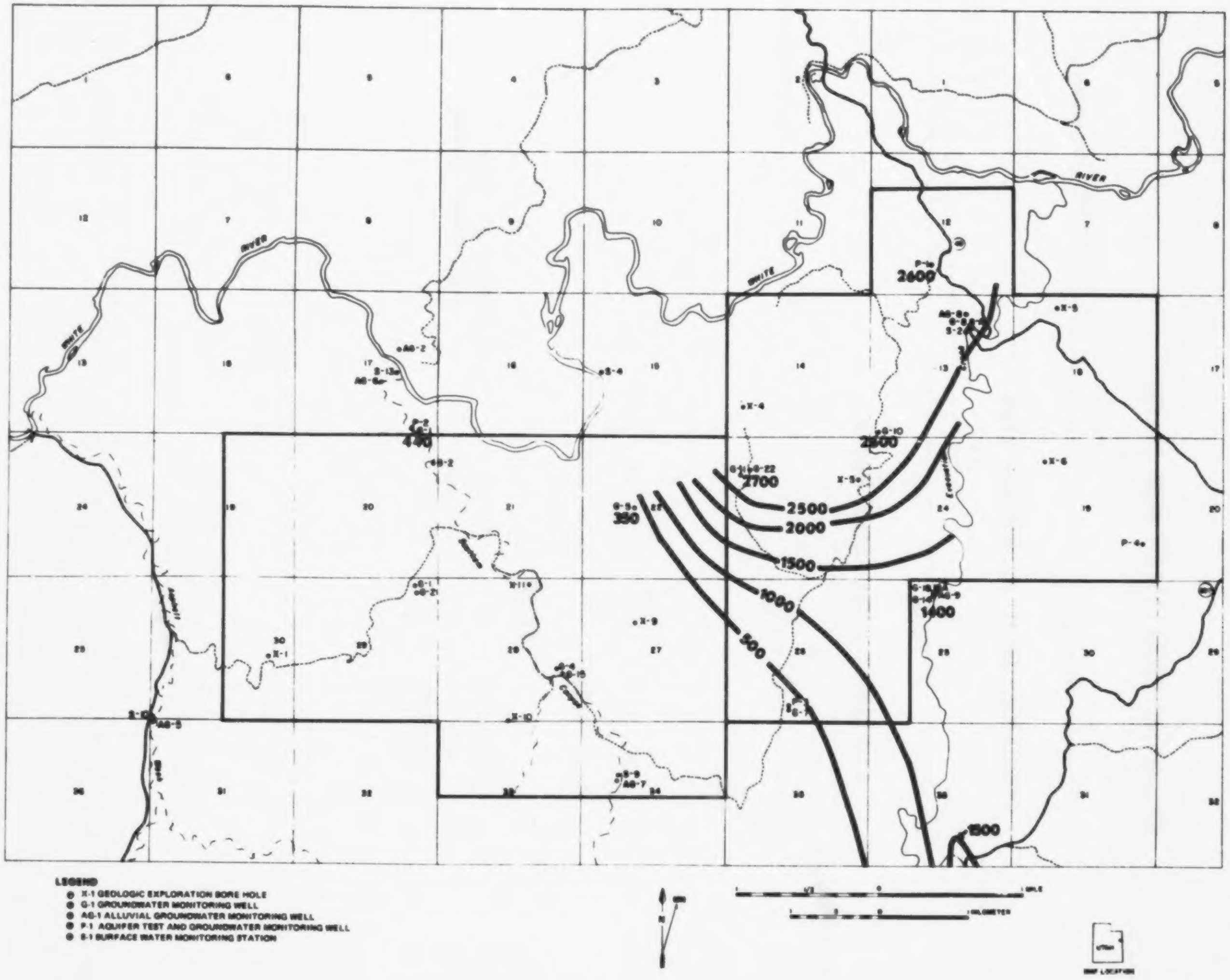

WHITE RIVER
2400
(BA) 2040
2400
200
2500
2000
1500
1000
800
710
310
1100
1500
480
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
MAP LOCATION

Figure 6-22. Mean sulfate concentration (mg/l) in the Bird's Nest Aquifer, November 1974 (data from WRSP, 1976b; map by GE—TEMPO).



2700
2600
2500
2000
1500
1100
1000
500
490
RIVER
WHITE RIVER
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
UTAH
MAP LOCATION

Figure 6-23. Mean sulfate concentration (mg/l) in the Bird's Nest Aquifer, March 1975 (data from WRSP, 1976b; map by GE–TEMPO).



WHITE RIVER
2600
2800
2700
2500
2000
1500
1000
500
350
1400
1500
400
P-2
X-4
X-5
X-6
X-9
X-10
G-10
P-4
AG-2
S-4
LEGEND
X-1 GEOLOGIC EXPLORATION BORE HOLE
G-1 GROUNDWATER MONITORING WELL
AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
S-1 SURFACE WATER MONITORING STATION
MILE
KILOMETER
UTAH
MAP LOCATION

Figure 6-24. Mean sulfate concentration (mg/l) in the Bird's Nest Aquifer, November 1975 (data from WRSP, 1976b; map by GE—TEMPO).

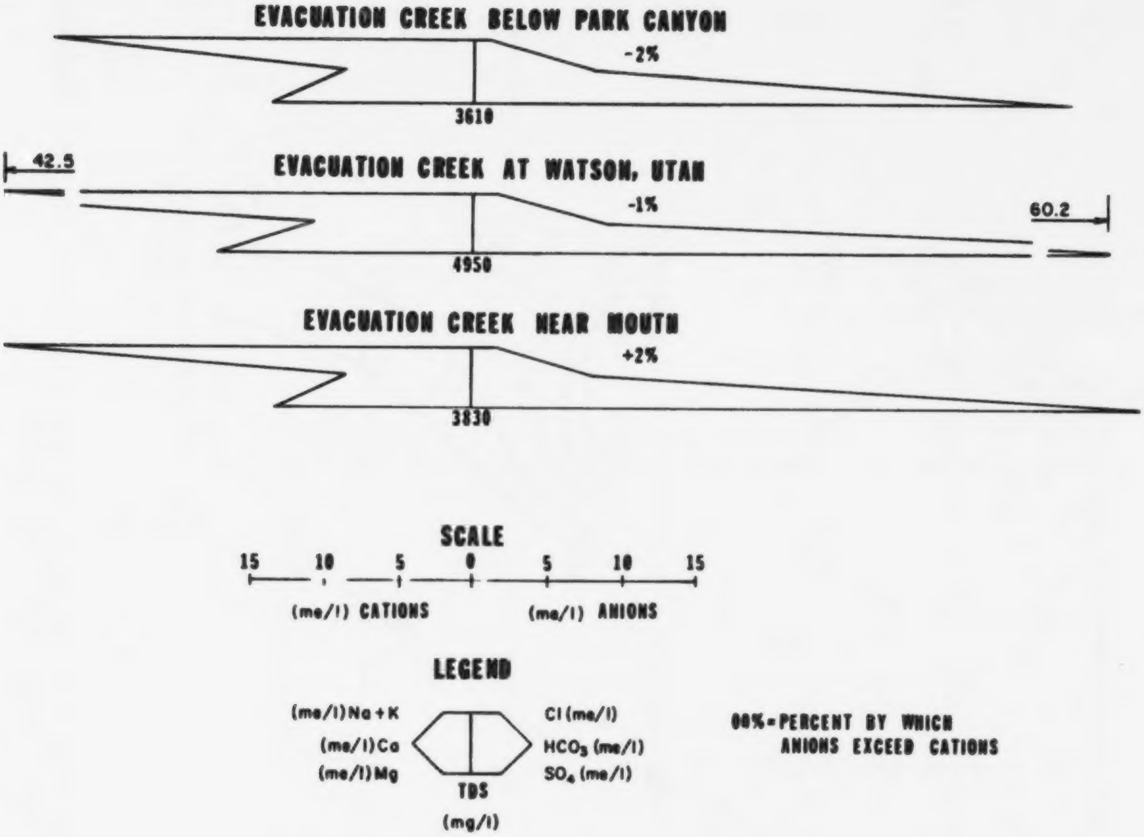


Figure 6-25. Distribution of major ions in Evacuation Creek during 1975 water year base-flow period (WRSP, 1976b).

SECTION 7

INFILTRATION POTENTIAL OF WASTES AT THE LAND SURFACE

INTRODUCTION

This section and the two which follow it address the mobility of pollutants (identified in Sections 2 and 3) in the hydrogeologic framework of the study area (described in Sections 5 and 6). The study area has been arbitrarily segmented into three parts: spent shale disposal area, plant process area, and retention dam sites.

SOIL PROPERTIES

According to Philip (1969), *infiltration* is defined "as a process of the entry into the soil of water made available (under appropriately defined conditions) at its surface. This "surface" may be the natural, more or less horizontal upper surface of the soil; or it may be the bed of a natural or artificial furrow or stream..." The infiltration properties of native soils on the tract are briefly described in the following paragraphs.

Nearly all of the soils on the oil shale tracts fall into the category of channery sandy loams. Only the soils of the White River valley bottom have a predominantly silty or clay texture. In general, the sandy loams have moderate to very slow infiltration rates. Infiltration through the silty clay soils is very slow. The tract soils, shown in Figure 5-5, have been classified into hydrologic soil groups (Table 7-1). The soil groups (U.S. Department of Agriculture, 1972) are as follows:

A. (Low runoff potential). Soils having *high infiltration rates* even when thoroughly wetted and consisting chiefly of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water transmission.

B. (Moderately low runoff potential). Soils having *moderate infiltration rates* when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well drained to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. (Moderately high runoff potential). Soils having *slow infiltration rates* when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

TABLE 7-1. ESTIMATED AND MEASURED SOIL PROPERTIES SIGNIFICANT TO ENGINEERING REQUIREMENTS[a]

Soil	Slope range (%)	Depth to bedrock (cm)	Texture class	Unified	AASHO	Liquid limit	Plastic limit	Permeability (in/h)	In/In available water capacity	pH	EC[d] (mmhos/cm)	Shrink-swell potential	Hydrologic soil groups
A	3 to 40	30 to 50	Channery loam	SM GC	A-2-4	24-33	NP-0	1.0-2.5	0.09-0.11	7.5-8.7	0.4-5.4	Low	C (moderately high runoff potential)
As	5 to 60	30 to 50	Channery sandy loams	SM GM	A-2-4	24-36	NP	1.5-3.0	0.1[c]	8.1-8.5	0.3-6.0	Low	C (moderately high runoff potential)
B[b]	5 to 40	5 to 25	Channery loams	SM GM	A-2-4	20-30	NP	1.0-2.5	0.1[c]	7.5-8.2	0.7-3.0	Low	D (high runoff potential)
Bs[b]	10 to 60	5 to 25	Channery sandy loams	SM GM	A-2-4	20-30	NP	1.5-3.0	0.1[c]	7.5-8.3	0.7-2.5	Low	D (high runoff potential)
Ds	5 to 10	150+	Sandy loam to channery sandy loam	SM	A-2-4	20-30	NP	1.0-2.4	0.12-0.14	7.9-8.3	1.0-19.0	Low	B (moderately low runoff potential)
E	5 to 10	150+	Fine sandy loams to loams	ML CL SM	A-4 A-6	20-27	NP-8	1.0-2.5	0.14-0.16	7.7-8.6	0.4-18.0	Low	B (moderately low runoff potential
F[b]	3 to 7	10 to 40	Loamy sands	SM	A-2	20-30	NP	2.0-4.0	0.1[c]	8.1-8.5	0.3-0.6	Low	D (high runoff potential)
N[b]	5 to 10	150+	Fine sandy loam surface silty clay loam subsoil	CL	A-4 or A-6	20-30	5-15	0.05-0.20	0.14-0.16	8.1-8.9	5.0-15.0	Moderate	D (high runoff potential)
W	0 to 2	150+	Silt loams to silty clay loams - some sands	CL SM	A-4 A-6	20-47	2-16	0.20-1.50	0.16-0.18	8.0-8.3	1.5-28.0	Moderate	B (moderately low runoff potential)

[a] From White River Shale Project, 1976b

[b] Estimate

[c] Less than

[d] Electrical conductivity

D. (High runoff potential). Soils having *very slow infiltration rates* when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The infiltration data on which the hydrological classification was made are included in Table 7-1. On the basis of this classification, the soils map (Figure 5-5) has been redrawn, regrouping the soil categories into hydrologic categories (Figure 7-1). From Figure 7-1, it may be seen that most of the proposed processed shale pile is underlain by soils in the D and C categories, indicating slow to very slow infiltration, and by bare rock. The main drainage channels are lined with soils in the B category; these soils are suitable for revegetation and will be removed and stockpiled before they are covered by the advancing shale pile (WRSP, 1976a).

As shown by the criteria used to categorize the hydrologic properties of soils, the relatively shallow depths and steep slopes of many of the soils on the tracts will restrict infiltration. In particular, such soils will have a low water-storage capacity (relative to deep soils) and consequently a reduced infiltration capacity. Water will run off the surface into depressions or stream channels and will possibly also produce perched water tables above bedrock. From Table 7-1, shallow soils (depths less than 50 cm) on the tract include: A (channery loams), As (channery sandy loams), B (channery loams), Bs (channery sandy loams), and F (loamy sands). Deeper soils (greater than 150 cm) include: Ds (sandy loam to channery sandy loam), E (fine sandy loams to loams), N (fine sandy loam surface, silty clay subsoil), and W (silt loams to silty clay loams). Note that the N-type soil with a silty clay subsurface may also develop a perched water table condition at the interface of two soil types.

PROCESS AREA

Potential sources that may infiltrate the soils of the process area include: stockpiled soil leachate and runoff; treated effluent and storm runoff in a proposed holding basin; water reservoir storage; product tankage leaks; leaks from the sulfur and ammonia storage tanks; stockpiled raw shale runoff and leachate; and possibly explosive residues.

Predominant soil types in the process area include: Bs(3) and Bs(5), shallow channery and flaggy sandy loams; D, sandy loams; As(1), shallow channery sandy loam; A(2), shallow channery loams. In addition, a large proportion of the area is classified as rock, R. Infiltration will be minimal in the rocky areas except where fractures or joints exist. In addition, from Table 7-1 and Figure 7-1, infiltration will be restricted in the following soils because of shallow depths and relatively steep slopes: A(2), As(1), Bs(3), and Bs(5). In contrast, infiltration will be moderately high in the sandy loam soils which are classified as B under the hydrologic soil grouping (see Figure 7-1). The latter soils are located in stream channels and will receive surface and possibly subsurface drainage from higher areas. Consequently, pollutants leaching from other areas probably would concentrate in

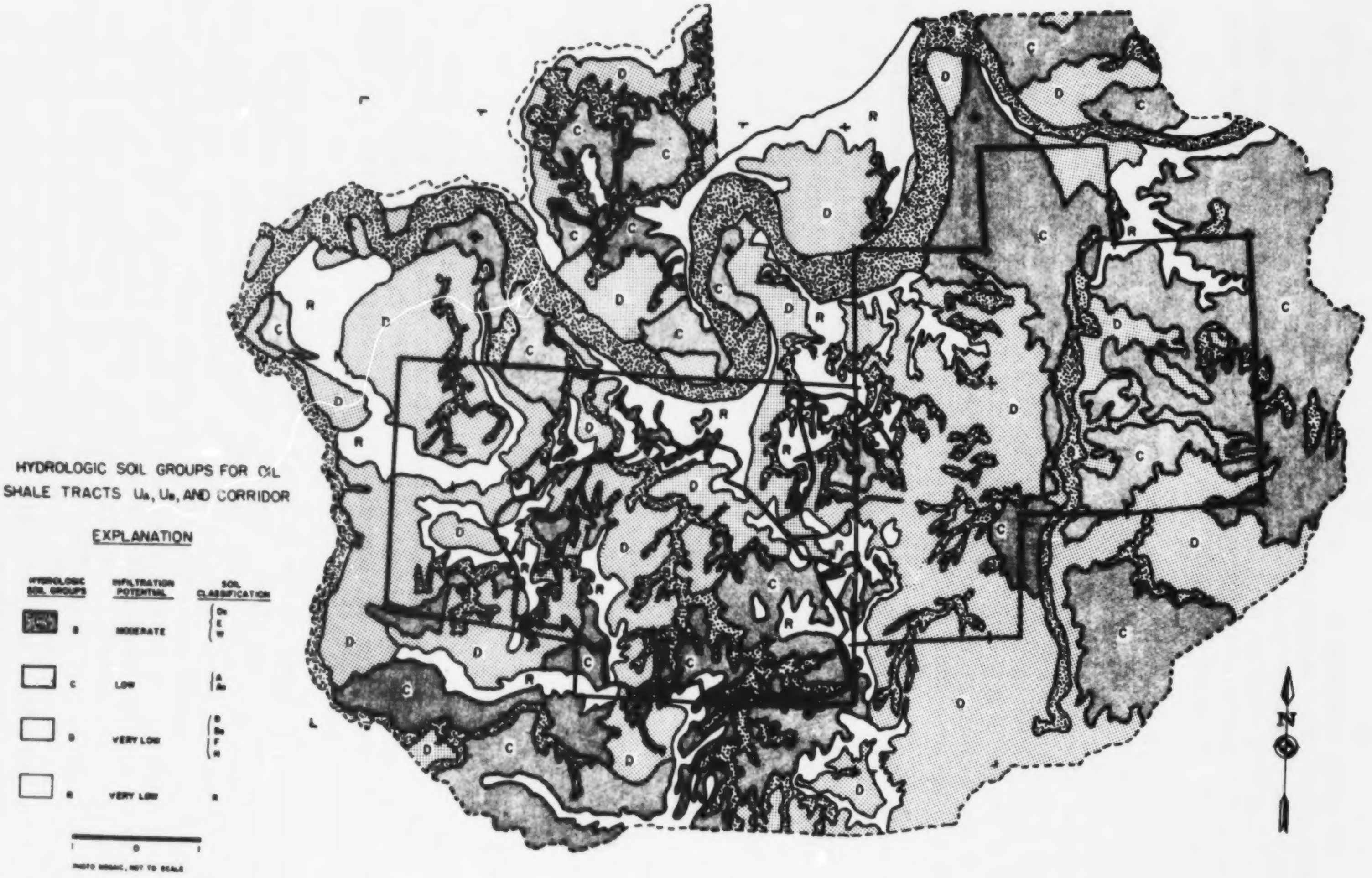

HYDROLOGIC SOIL GROUPS FOR OIL SHALE TRACTS Ua, Ub, AND CORRIDOR
EXPLANATION
HYDROLOGIC SOIL GROUPS
INFILTRATION POTENTIAL
SOIL CLASSIFICATION
B
MODERATE
Dn
E
W
C
LOW
A
An
D
VERY LOW
B
Bn
F
H
R
VERY LOW
R
0
PHOTO MOSAIC, NOT TO SCALE
N
C
D
R
T
L

Figure 7-1. Hydrologic soils map (data from WRSP, 1976b).

these channel deposits.

Infiltration or seepage may occur through the base of the waste water holding pond and water reservoir, depending on the type of sealant used. The sealants to be used are, at present, unspecified. Because of the shallow soils, seepage would occur into the underlying bedrock, the Uinta sandstones. Consequently, flow possibly would be restricted to fissures and small cracks, unless by chance the ponds are located on large cracks. Small cracks probably would seal in time with organic, benthic deposits.

SPENT SHALE DISPOSAL AREA

The disposal area in Southam Canyon will incorporate sanitary landfills for the burial of solid wastes and the spent shale pile. It is envisioned that initially a landfill will be located in side canyons, ahead of the spent shale pile. Later, landfills will be incorporated within the spent shale pile.

Solid wastes presently proposed (WRSP, 1976a) to be deposited in sanitary landfills include: construction materials, trash and garbage, spent converter catalysts, spent reformer catalysts, spent methanation catalysts, deactivated carbon filter cakes, spent Claus unit catalyst, diatomaceous earth filter cakes, spent HDN catalyst, catalyst support materials, spent guard bed catalyst, spent HDS catalyst, and elemental sulfur slurry. Sources deposited within the spent shale pile include the above, when landfill materials are incorporated into the pile, and in addition include the following: raw shale dust, discarded alumina balls, water treatment sludge, processed shale, treated effluent and storm runoff, and leachate pumped back from the retension dams.

General Landfill

The potential for leachate production by infiltration into the sanitary landfill was estimated using a water balance method described by Fenn, Hanley, and DeGeare (1975). Their approach is a modification of a technique originally proposed by Thornthwaite and Mather (1957). The rationale of Fenn, Hanley, and DeGeare (1975) in using the water balance method was: "The infiltration fraction of precipitation is the principal contributor to leachate generation from a sanitary landfill. The infiltration into the soil cover and any subsequent percolation down to the solid waste will be determined by surface conditions of the sanitary landfill and by the climatological characteristics of the site's location...the water balance method is presented as a satisfactory and feasible procedure for performing the required task."

Details of the water balance calculations used in this study are presented in Appendix A. Basically, the water balance method is an application of the hydrologic equation to the soil surface. Inputs to the system consist of precipitation and irrigation. The outputs comprise evapotranspiration losses, surface runoff, and deep percolation. The storage component includes the pore space of the soil. The method of Thornthwaite and Mather (1957) is a bookkeeping procedure that determines soil-water surplus or deficiencies. The rationale of the procedure as applied to landfills by Fenn, Hanley, and DeGeare (1975) is that surplus soil-water above field capacity is available for either runoff or deep percolation. Field capacity is generally regarded as that water content at which gravitational and capillary effects are in approximate balance. Thornthwaite and Mather (1957) include a method for calculating evapotranspiration. However, the method of Blaney-Criddle is more satisfactory for western regions and was used in this and the following analyses.

Assumptions of this analysis include:

1. Soil surface of the landfill will have a sandy loam texture, with the following properties: permeability, 2.5 to 5 cm per hour (1 to 2 inches per hour); apparent specific gravity, 1.50; field capacity, 14 percent; permanent wilting percentage, 6 percent; and water stored between the two limits is 120 mm per meter (1.4 inches per foot) (Israelsen, 1962).
2. Total depth of cover: 1.0 meter.
3. Applied water in excess of field capacity goes to runoff or percolation.
4. Snow melt runoff does not occur. Fenn, Hanley, and DeGeare (1975) point out that surface runoff may be assumed to be negligible for the dry months in an arid climate. For our analysis, we have assumed that runoff will be zero throughout the entire year.

The value of 120 mm per meter (1.4 inches per foot) was calculated with the following equation (Fenn, Hanley, and DeGeare, 1975).

$$\frac{d}{D} = A_s \frac{\Delta P_w}{100} , \qquad (1)$$

where

d = depth of water in soil

D = depth of soil

A_s = apparent specific gravity

$\frac{\Delta P_w}{100}$ = difference in water content between the permanent wilting percentage and field capacity, dry weight basis

$= \frac{(14 - 6)}{100}$ = 8 percent.

Results of the water balance calculations for the landfills are shown in Table 7-2. Based on the assumptions used to calculate the moisture surplus shown on the table, it appears that infiltration into the surface of the landfill will be negligible. Water which neither runs off nor percolates deeply is held in storage near the surface until lost through evapotranspiration.

TABLE 7-2. MONTHLY WATER BALANCE ON OIL SHALE TRACTS—LANDFILL CASE

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T[a]	15.2	24.8	33	46.1	57.2	63.8	73.1	67.9	60.3	45.2	34.4	24.4
PET	0	0	47	70.6	100	115	103	110	86.7	60	39.4	0
P[b]	1.39	16.2	35.7	86.7	37.5	9.6	22.4	9.6	39.7	0	0	0
P - PET	+1.39	+16.2	-11.3	16.1	-62.5	-105.4	-80.6	-100.4	-47	-60	-39.4	0
Σ NEG(P-PET)		-158 [c]	-169.3	-119[d]	-181.5	-286.9	-367.5	-467.9	-514.9	-574.9	-614.3	
ST		35	31	47.1	29	12	6	3	2	1	1	
Δ ST			-4	16.1	-18.1	-17	-6	-3	-1	-1	0	
S			0	0	0	0	0	0	0	0	0	

Assumptions: 1 meter of soil: available water = 120 mm/meter; total soil moisture retention = 120 mm/meter

T = temperature (°F)

PET = potential evapotranspiration (mm)

P = precipitation and applied water (mm)

Σ NEG (P - PET) = accumulated potential water loss (mm)

ST = storage (mm)

Δ ST = change in storage

S = moisture surplus

[a] Temperature data for 1976, Vernal Airport

[b] Precipitation data for 1976, reported at Vernal Airport and adjusted to project site

[c] Calculated by method of successive approximations (see Appendix B)

[d] When a positive value of P - PET occurs between two negative values, the Σ NEG (P - PET) value is found by a method discussed by Fenn et al. (1975)

Processed Shale Pile

General Features—

The proposed spent shale pile on the U-a and U-b tracts will be composed of a mixture of processed shales from the Paraho and the TOSCO retorting processes. Paraho-processed shale is somewhat similar to the USBM-processed shale (see Figure 7-2); since some data have been published on the USBM-processed shale that are not available for the Paraho-processed shale, data on the USBM shale are included in this report. Particle size distribution data for these types of processed shales and the combined (15:85 TOSCO:Paraho) wastes are presented in Figure 7-2.

The Detailed Development Plan (WRSP, 1976a) indicates that the ratio of TOSCO- to Paraho-processed shale will be approximately 15:85. The mixture of very fine TOSCO- and coarser Paraho-processed shales will result in a poorly sorted material that will have a lower permeability than the pure Paraho-processed shale. From the diagram of soil texture in Figure 7-3, it may be seen that the Paraho-processed shale falls into the category of a sand and the TOSCO-processed shale that of a silt. The 15 percent TOSCO and 85 percent Paraho mixture is a sandy loam. Although the sandy loam classification was used in determining hydrologic properties for the water balance equation, it should be noted that 29 percent of the total is gravel, which is not included in the soil classification scheme (Figure 7-3). Hence, actual permeabilities may be somewhat greater than indicated here.

Figure 7-4 illustrates the permeability ranges of TOSCO II and USBM spent shales in relation to other earth materials. Although permeability and infiltration rate are not strictly equivalent, permeability (hydraulic conductivity) provides a reasonably good estimate of the asymptotic infiltration rate in one-dimensional flow systems. From Figure 7-4, both spent shale materials would be expected to exhibit permeability similar to that of poor aquifers, with specific permeabilities between about 10^{-1} and 10^{-2} darcy. From these considerations, relatively low infiltration rates for the processed shale pile may be inferred.

The infiltration characteristics of spent shale may be related somewhat to the ease of wetting; i.e., the presence of possibly hydrophobic organics might inhibit wetting and, consequently, infiltration. Tract development plans (WRSP, 1976a) indicate, for example, that resistance to wetting of TOSCO-processed shale has been reported in the literature. However, Utah Fischer assayed and calcined shales have not shown resistance to wetting. The plan also indicates that Paraho-processed shale "...took water readily and appeared to be porous." Thus resistance to wetting is not expected to be significant in the processed shale pile as proposed for Southam Canyon.

Infiltration During Construction—

Two aspects of shale pile construction should be considered in relation to infiltration: (1) infiltration during construction, and (2) infiltration on the completed, contoured, and revegetated pile. During disposal, spent shale will be deposited in Southam Canyon in a fanlike progression away from

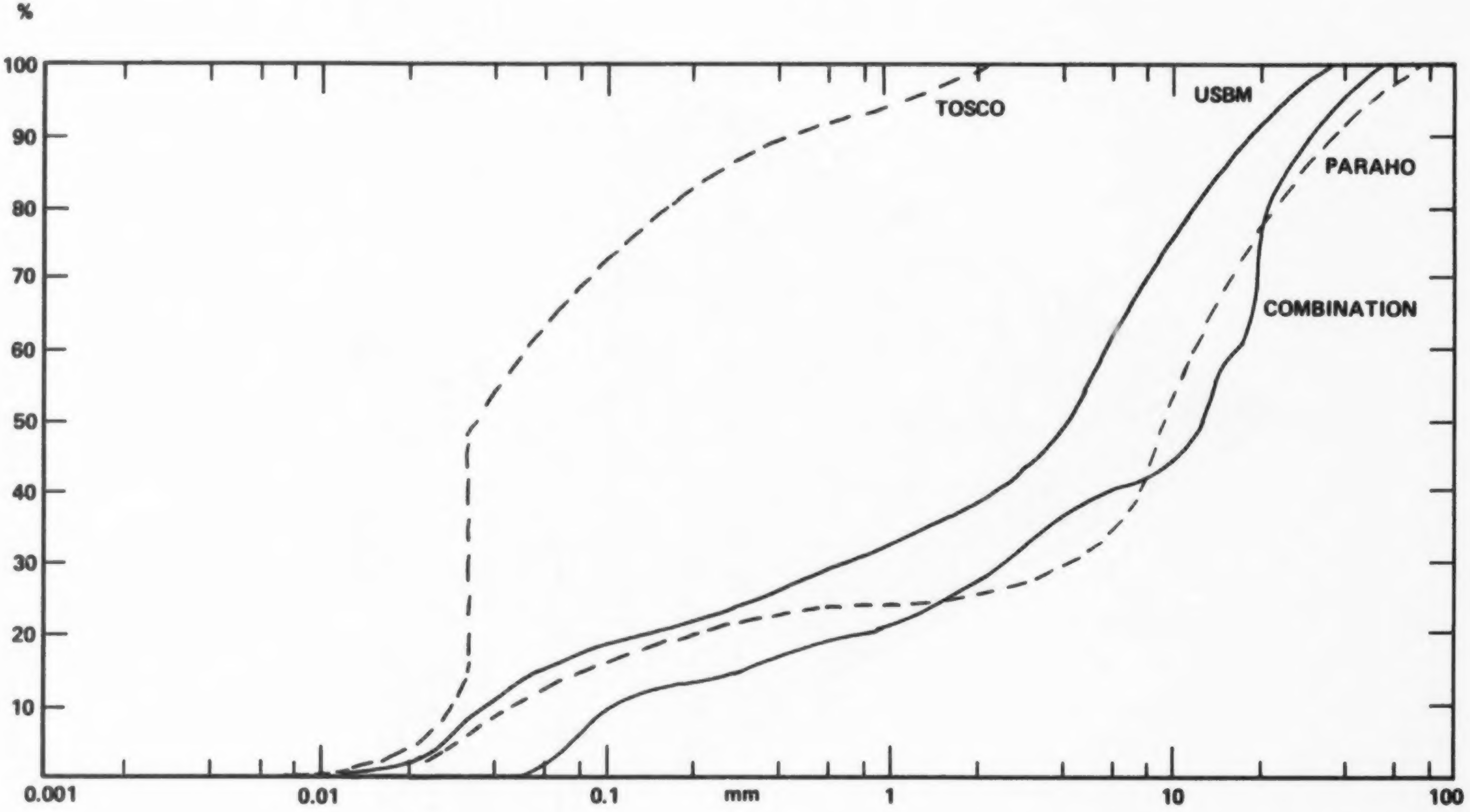


Figure 7-2. Cumulative grain-size distribution of processed oil shale.

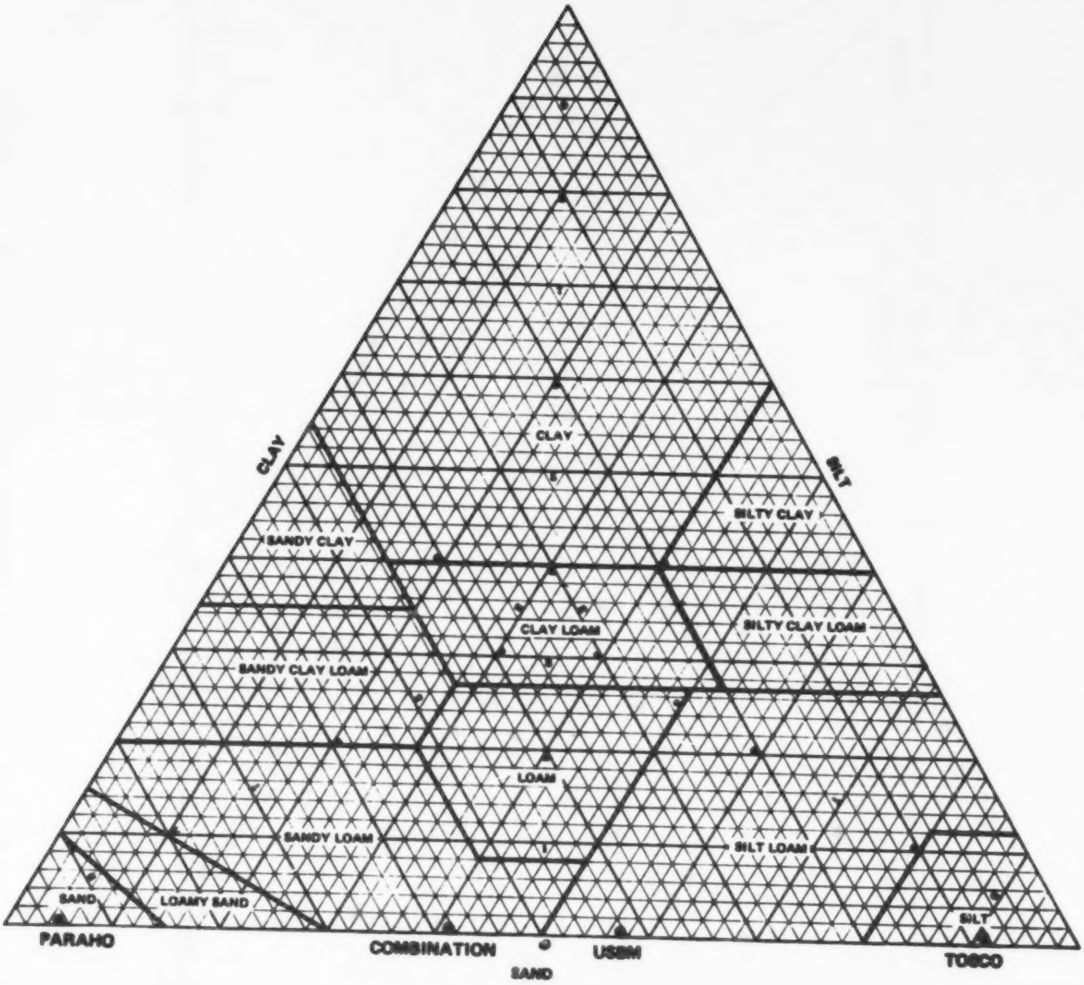


Figure 7-3. Soil texture of processed oil shales.

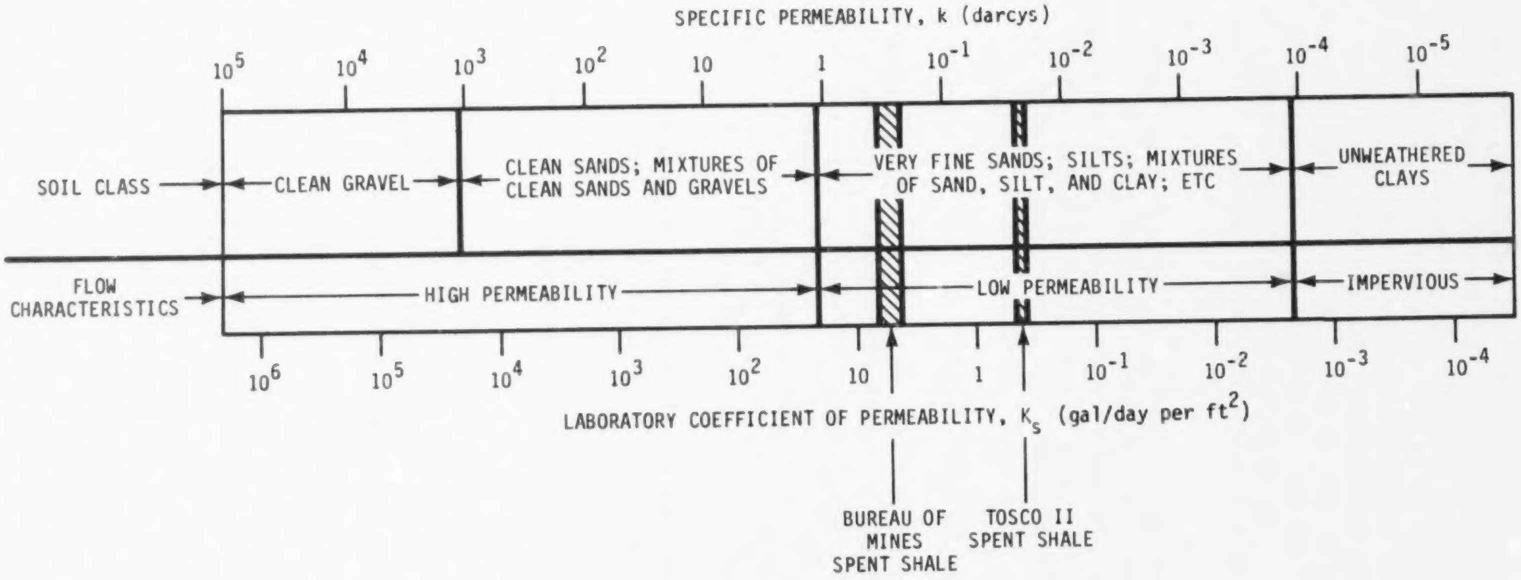


Figure 7-4. Permeability ranges of TOSCO II and Bureau of Mines spent shale (data from Ward et al., 1971 and 1972; figure adapted from Todd, 1959).

the process area. The deposited wastes will gradually increase in lateral and vertical extent. In other words, the infiltration "surface" will be continually changing. Water will be sprayed onto the spent shale to bring the total water content to 10 percent by weight. In addition, rain and snow will wet the surface. To estimate the potential amount of infiltration during construction, a water balance was calculated. Assumptions used were: (1) sandy loam texture in the spent shale; (2) a "soil" depth of about 1 meter (3 feet); (3) initial water content 10 percent by weight; (4) field capacity 18 percent by weight (WRSP, 1976a); (5) apparent specific gravity of spent shale, 1.50; (6) runoff is negligible; and (7) total available storage of 120 mm in 1 meter of soil.

For this evaluation, water storage in the spent shale is identical to that in the landfill soil, and the same water balance given in Table 7-2 applies. Additional details are explained in Appendix A. Again it appears that the amount of surplus water available for deep percolation remains zero throughout the year. However, piles of snow might contribute locally to infiltration during melting.

Infiltration of Completed Disposal Pile—

Several factors should be taken into account when evaluating infiltration potential through the completed spent shale pile. The top of the shale pile will be diked around the edge to prevent runoff. The pile face will include reverse-sloped benches, again to minimize runoff (Section 2). Thus it may be expected that there will be no runoff from the top of the shale pile and very little runoff from the sides. Nearly all of the precipitation falling on the shale pile will either infiltrate or evaporate.

Eventually, the spent shale pile will be revegetated. Trenches about 1 meter deep (3 to 4 feet) will be constructed along the contour on the slopes and on the flat top of the pile (see Figure 2-10). The trenches will be backfilled with soil from the process area and planted. It is anticipated that vegetation will eventually spread throughout the surface of the entire pile.

The salt content of the pile is so high that leaching will be required to flush the salts from the root zone of prospective vegetation. Cook (1974) indicated that at least 1.5 meters (5 feet) of water may be required to render the shale suitable for use as a plant growth medium.

Water harvesting will be practiced on the shale pile as a method of irrigating the plantings. As shown on Figure 2-10, the surface of the pile will be sculpted and temporarily sealed to direct water into the trenches. Polyvinyl acetate, paraffin, and polyethylene are some of the alternative sealant materials (McKell, 1976). Until decaying, these sealants would prevent infiltration between the trenches. Later, as vegetation spreads out from the trenches, decomposition of the sealant would permit entry of water into the area between trenches.

In summary, the establishment of vegetation on the spent shale pile may consist of the following successive stages: (1) leaching salts from the top

0.6 to 0.9 meter (about 2 to 3 feet) of the pile; (2) constructing soil trenches and laying down water-harvesting materials; and (3) eventual deterioration of the surface sealant. Infiltration into the pile will be related to these stages.

A water balance was prepared to estimate infiltration into the completed spent shale pile during the first stage, involving leaching of surface salts. Assumptions used were identical to those above for infiltration into the pile during construction. In addition, it was assumed that 1,524 mm (5 feet) of water was added in June to the monthly precipitation of about 10 mm, to give a total of about 1,534 mm applied to the surface. Results are given in Table 7-3. The table shows that a surplus of about 1,328 mm of water resulted from applying 1,534 mm of water in June. This excess would move into the vadose zone. Using the relationship

$$D = \frac{d(100)}{A_s \ \Delta P_w} , \qquad (2)$$

it is calculated that the surplus 1,328 mm would drain 11.1 meters (about 36 feet) below the upper 1 meter. Considering that the completed shale pile may be as much as 150 meters (500 feet) deep, it appears that leached pollutants will reach the interface between the spent shale pile and natural ground surface only from regions near the toe of the pile.

The soil trenches will essentially represent line sources for the entry of surplus water into the vadose zone. Only a conceptual picture of the trench arrangement is provided in present development plans (WRSP, 1976a). It was, therefore, necessary to make some assumptions about the construction of trenches; the distance between trenches; and the slope of the water-harvesting surface.

As a first estimate, it was assumed that the trenches will be constructed with straight sides, as shown on Figure 2-10 (this may be difficult to achieve in practice because of the instability of the spent shale). Dimensions of the hypothetical trenches are assumed to be 1 meter wide and 1 meter deep (about 3 feet by 3 feet). As a further simplification (in the ensuing water balance), only the water-harvesting system for flat areas is considered. For these areas, it is assumed that the collecting surface rises at a slope of 10:1 for a distance of 5 feet (1.52 meters) in both directions away from the trench (see Figure 2-10). In other words, the trenches will receive drainage from 10 feet (3.05 meters) of lateral surface.

A water balance was calculated for soils in trenches within the flat water-harvesting areas. It was assumed that the properties of soils in the trenches will be identical to those for soils of the sanitary landfills, i.e., sandy loam texture; apparent specific gravity, 1.50; field capacity, 14 percent; wilting point, 6 percent; total water stored in a meter of soil, 120 mm. In addition, it was assumed that all precipitation falling on the sloping collection surface and trench will be applied as an equivalent head of water over the trench.

TABLE 7-3. MONTHLY WATER BALANCE ON OIL SHALE TRACTS—LEACHING CASE

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T[a]	15.2	24.8	33	46.1	57.2	63.8	73.1	67.9	60.3	45.2	34.4	24.4
PET	0	0	47	70.6	100	115	103	110	86.7	60	39.4	0
P[b]	1.39	16.2	35.7	86.7	37.5	1534	22.4	9.6	39.7	0	0	0
P - PET	1.39	16.2	-11.3	16.1	-62.5	1419	-80.6	-100.4	-47	-60	-39.4	0
Σ NEG(P-PET)		(-158)[c]	-169.3	-119[d]	-181.5	0	-80.6	-181	-228	-288	-327.4	
ST		35	31	47.1	29	120	47	29	20	12	9	
Δ ST			-4	16.1	-18.1	91	-83	-18	-9	-8	-3	
S			0	0	0	1328	0	0	0	0	0	

Total soil moisture retention = 120 mm/meter

T = temperature (°F)

PET = potential evapotranspiration (mm)

P = precipitation and applied water (mm)

Σ NEG (P - PET) = accumulated potential water loss (mm)

ST = storage (mm)

Δ ST = change in storage

S = moisture surplus

[a] Temperature data for 1976, Vernal Airport

[b] Precipitation data for 1976, reported at Vernal Airport and adjusted to project site

[c] Calculated by method of successive approximations (see Appendix A)

[d] When a positive value of P - PET occurs between two negative values, the Σ NEG (P - PET) value is found by a method outlined by Fenn et al. (1975)

Results of the water balance area are shown in Table 7-4. Note that precipitation depths (P) for the water-harvesting case are about four times greater than for the landfill case (Table 7-2). Precipitation amounts during January and February, when temperatures are below zero, were considered to infiltrate into the trench in March. From the table, surplus soil water would be available in March, April, and May. The total surplus is about 420 mm.

From relationship (2), it was calculated that 420 mm (16.5 inches) of water would move 3.5 meters (11.5 feet) below the trench. Again, assuming that the spent shale pile may be as much as 150 meters (500 feet) in thickness, the movement of solutes during a single year will not be significant. However, in 10 years, solutes would penetrate to a depth of 35 meters (115 feet), assuming that precipitation remains the same. Once the sealant deteriorates, infiltration will then occur over the entire surface. That is, the water balance will shift to the case shown on Table 7-2. The extent of deep percolation beneath the revegetation trenches will depend upon the longevity of the surface seal.

In calculating the depths of penetration of water for the water-harvesting case and other cases, it was assumed that flow was one-dimensional. In reality, flow would be two-dimensional from a line source, such as the revegetation trenches. The depth of water penetration would not be as great as calculated because of lateral flow. In time, however, water infiltrating from adjoining trenches would merge and flow would then occur essentially in the vertical direction.

For trenches on the sloping surface of the spent shale pile (see Figure 2-10), it is assumed that the water balance on Table 7-4 applies. In this case, harvested water moving through the trenches at lower elevations would seep out of the toe of the pile, or flow into the underlying vadose zone through fractures and bedding planes. Leachate moving from the toe of the pile would drain into the Southam Canyon retention dam.

RETENTION DAMS

Retention dams are planned to collect leachate from the Phase II spent shale pile, from the Phase III and IV piles (the Southam Canyon retention dam), and from the sanitary landfill.

The Phase II retention dam will be located in the northeast quarter of Section 28. From Figure 5-5, soils at the dam site are predominantly type As(1), shallow channery loams, and type Bs(4), shallow channery and flaggy sandy loams. From Table 7-1, these soils are less than 50 cm (1.6 ft) deep and belong in hydrologic group C, with low infiltration potential. Eventually, leachate retained by the dam would fill up the small storage capacity of the soils with the excess running off. Leachate could also seep into the dam, creating a free surface within the structure. Unless an effective cutoff wall is provided, leakage could occur out of the downstream face, possibly introducing leachate onto soils and channel deposits. Again, the soils downstream of the dam, in Southam Canyon, are mainly shallow channery and flaggy sandy loams with an admixture of deeper sandy loams. The latter soils are classified hydrologically as B, with moderately high infiltration potential. Leachate movement into the vadose zone would be a problem with these soils.

TABLE 7-4. MONTHLY WATER BALANCE FOR OIL SHALE TRACTS—WATER-HARVESTING CASE

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T^a	15.2	24.8	33	46.1	57.2	63.8	73.1	67.9	60.3	45.2	34.4	24.4
PET	0	0	47	70.6	100	115	103	110	87	60	39	0
P^b	6	65	143	348	151	39	90	39	159	0	0	0
P - PET	6	65	96	277	51	-76	-13	-71	72	-60	-39.4	
Σ NEG(P-PET)					(0)	-76	-89	-160	-20[c]	-80	-119.4	
ST	47	47	120	120	120	67	60	34	106	65	47	47
Δ ST			73	0	0	-53	-7	-26	+72	-41	-18	
S			94	277	51	0	0	0	0	0	0	

Total soil moisture retention = 120 mm/meter

T = temperature (°F)

PET = potential evapotranspiration (mm)

P = precipitation and applied water (mm)

Σ NEG (P - PET) = accumulated potential water loss (mm)

ST = storage (mm)

Δ ST = change in storage

S = moisture surplus

[a] Temperature data for 1976, Vernal Airport

[b] Precipitation data for 1976, reported at Vernal Airport and adjusted to project site

[c] When a positive value of P - PET occurs between two negative values, the Σ NEG (P - PET) value is found by a method outlined by Fenn et al., 1977

No information is provided on the location of the proposed landfill and retention dam other than they will be located in a side canyon. As shown by the water balance, leachate generation is not expected in the landfill proper. However, some runoff from the sloping face of the landfill may occur, possibly producing leachate in the toe of the fill. Such leachate would flow downstream and be retained by the dam. If conditions are similar to those for the Phase II retention dam, infiltration of leachate might occur into the shallow soils. Similarly, seepage through the retention dam could introduce leachate into deeper sandy soils with greater infiltration potential.

The Southam Canyon retention dam will collect leachate and surface runoff from the spent shale pile. The quality of this water probably will be extremely poor, with high TDS, organics, and trace elements (see Section 8). Development plans call for removing soils immediately upstream of the retention dam and placing an impermeable membrane on the exposed Uinta Formation. If the membrane fails, leakage will occur into the underlying sandstones. Downward movement will be restricted to cracks and fissures. Consequently, unless a fracture is exposed, infiltration should be minimal.

The proposed retention dam probably will be constructed as an earthen structure, with a cutoff wall. Seepage through the dam conceivably could bypass the cutoff wall and exit from the downstream face. Leachate would then flow into the White River alluvium. The infiltration potential of this alluvium is probably quite high. Furthermore, surface runoff of leachate might, in time, drain into the White River.

SUMMARY OF INFILTRATION POTENTIAL

Three principal areas of the tracts were identified in regard to infiltration potential: the process area, the processed shale disposal area, and the areas associated with retention dams. The soils of the process area are generally shallow with consequently poor infiltration characteristics. Pollutants applied or deposited onto these soils would possibly run off onto lower, deeper soils. Infiltration characteristics of the latter soils are good.

The processed shale disposal area will include sanitary landfills and the spent shale pile. A water balance on the landfill indicated that surplus gravitation water may not be available for movement beyond a depth of about 1.0 meter (about 3 feet). Similarly, infiltration may not be significant in the spent shale pile during construction under normal precipitation conditions. The completed pile will be shaped to minimize the surface runoff for both top and sides. During leaching of the spent shale pile, preparatory to eventual revegetation, as much as 1.5 meters (5 feet) of water may be flushed through the top 1 meter (3 feet) of the pile. A water balance indicated that surplus water might drain to a depth of about 11 meters (36 feet).

Water "harvested" from sealed surfaces on the pile and applied to soil trenches used for revegetation might produce surplus soil water during 3 to 4 months of the year. A water balance calculation showed that surplus water would move about 3.5 meters below the base at the trenches. If the sealant deteriorates within 10 years, the surplus would probably not migrate deeper than 35 meters. Leachate might seep from the toe of the pile as a result of deep percolation from trenches or the sloping face.

Retention dams will be constructed to trap leachate from the sanitary landfills, the Phase II spent shale pile, and the Phases III and IV spent shale piles. Leachate from the landfill would spread upon the shallow soils of Southam Canyon, which have poor infiltration characteristics. Seepage from the downstream face of the dam could drain onto deeper channel soils, which have good infiltration characteristics. The scenario for leachate infiltration from the Phase II retention dam is similar. Finally, leachate from the Phases III and IV spent shale piles is expected to be of very poor quality. Seepage through the dam (which will be provided with a cutoff wall) might introduce leachate into the White River alluvium and possibly also into the White River.

SECTION 8

MOBILITY OF POLLUTANTS FROM THE LAND SURFACE TO THE WATER TABLE

This section reviews factors relating to the mobility of pollutants in vadose zone sediments underlying the U-a and U-b oil shale tracts. First, a description of the vadose zone is presented. Secondly, mobility of pollutants characterized in Section 3 is reviewed.

VADOSE ZONE CHARACTERISTICS

The vadose zone is generally defined as that subsurface region extending from the land surface to the water table. For the oil shale tracts, the aquifer of concern (the Bird's Nest Aquifer) is confined. Nevertheless, for purposes of discussion, the indigenous vadose zone for the tracts is arbitrarily defined as that region extending from land surface to the interface between the confining Green River Formation mudstones and the Bird's Nest Aquifer. In vertical extent, the vadose zone consists of about 180 meters (600 feet) of Green River mudstones. Processing and disposal activities on the tracts will modify the indigenous vadose zone as follows.

Spent Shale Disposal Area

Spent shale will be deposited in a fanlike progression with Southam Canyon. The estimated total storage area will be 931 hectares (2,300 acres) and total depth will be about 150 meters (500 feet) above the floor of Southam Canyon. Native soil will be stripped from the storage area and stockpiled.

The definition of the vadose zone beneath the spent shale disposal area must be modified to account for changes during deposition of shale wastes; i.e., the vadose zone in this area will be of a dynamic nature as layer upon layer of spent shale is stacked above the surface of the Uinta Formation. The final configuration is represented schematically in Figure 8-1. The surface of the fabricated plus indigenous vadose zone will consist of a temporarily sealed layer and soil trenches for vegetation. The final total thickness of the vadose zone will be about 320 meters (1,100 feet).

Process Area

The process area will include facilities associated with the processing of raw shale and kerogen and peripheral facilities, including a treated effluent and storm runoff holding pond and a water reservoir. Piles of debris are expected, and soils stripped from Southam Canyon will be stockpiled. For details, see Section 2.

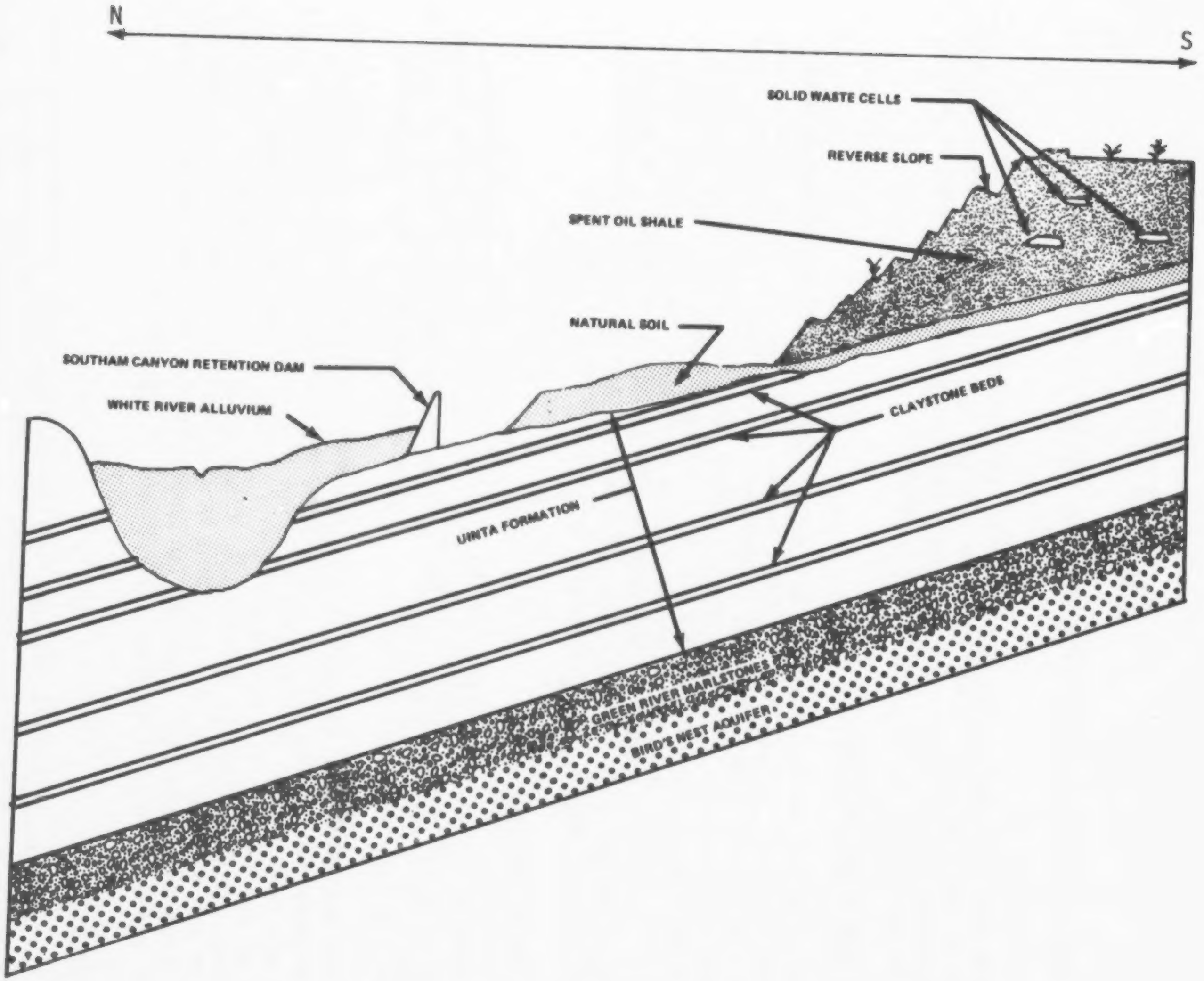

N
S
SOLID WASTE CELLS
REVERSE SLOPE
SPENT OIL SHALE
NATURAL SOIL
SOUTHAM CANYON RETENTION DAM
WHITE RIVER ALLUVIUM
CLAYSTONE BEDS
UINTA FORMATION
GREEN RIVER MARLSTONES
BIRD'S NEST AQUIFER

Figure 8-1. Schematic cross section of spent shale pile.

The shallow soils on the area will not be disturbed except by construction of facilities. Consequently, the above description of the vadose zone will be essentially valid for the process area.

Southam Canyon Retention Dam

A retention dam will be constructed at the outlet from Southam Canyon near the White River. Plans call for the removal of alluvium within the reservoir area and sealing of the basin. Consequently, the vadose zone at this site will extend downward through the Uinta and Green River Formations to the Bird's Nest Aquifer.

Hydraulic Properties of the Vadose Zone

The hydraulic properties of the vadose zone beneath the process area and Southam Canyon retention dam will be essentially the same as those for the indigenous vadose zone. For the spent shale disposal area, the hydraulic properties of both indigenous plus fabricated vadose zone must be considered.

Water and contaminant movement in the Uinta sandstones would occur primarily through cracks, fissures, and along bedding planes. Because of the constrictive nature of such cracks and openings, flow rates would probably be very slow. In addition, field observations indicate that cracks tend to pinch out within claystone beds in the Uinta Formation and where the Uinta sandstones merge with underlying Green River mudstones. The latter deposits serve as the overlying confining beds for the Bird's Nest Aquifer. Obviously water and pollutants seeping within the vadose zone must form saturated conditions above the confining bed with head higher in the saturated area than the head in the Bird's Nest Aquifer before movement into the aquifer will occur.

Because of the numerous claystone layers within the Uinta Formation and the Green River Formation, the polluted water moving through the vadose zone may form saturated perching layers. The regional structure would cause the water to flow down dip to the northwest. If the clay beds along which the pollutants were flowing are deep in the section, the pollutants would pass beneath the White River, eventually being dissipated within the Uinta Formation. If the perching beds were higher in elevation, the pollutants would flow into the alluvium of the White River valley and thus eventually into the river. The presence of evaporite deposits on sheltered outcrops of the claystone beds of the Uinta Formation indicates that, at the present time, small amounts of infiltration and movement of moisture along these beds are occurring.

Unlike the Uinta sandstones, the spent shale pile will be of a porous nature. Hydraulic properties, e.g., hydraulic conductivity of the spent shale, will depend on the compactive effort employed during construction. Permeability values for Paraho-processed shale are given in Table 8-1 as representative of possible values on the U-a and U-b tracts. As shown, permeability varies from a high of almost 5 meters (15.5 feet) per year to a low of 0.02 meter (0.08 foot) per year, depending on compactive effort and loading.

Water movement in the spent shale pile will probably occur mainly as unsaturated flow. Flux of pollutants will consequently be less than that for

TABLE 8-1. REGULAR PHYSICAL PROPERTIES OF COLORADO PARAHO-PROCESSED SHALE (WRSP, 1976a)[a]

Gradation (ASTM D422)	
Maximum particle size	2 in.
Clay size (0.005 mm)	2%
Silt and clay size (- No. 200 sieve)	22%
Sand size (No. 200 to No. 4 sieves)	23%
Gravel size (+ No. 4 sieve)	55%(b)
Plasticity (ASTM D423 and D424)	
Liquid limit	–
Plasticity index	nonplastic
Specific gravity (ASTM D854)	
Apparent (all sizes)	2.59(b)
Relative density(c) (ASTM D698)	
Dense (100%)	89.4 lb/ft^3 (d)
Loose (0%)	71.5 lb/ft^3 (d)

Compaction(c) (ASTM D698 and D1557)

	Compactive Effort	Optimum Moisture	Density (Max. at Optimum Moisture)
Low	6,200 ft-lb/ft^3	23.7%	88.0 lb/ft^3
Moderate	12,375 ft-lb/ft^3	22.0%	92.5 lb/ft^3
High	56,250 ft-lb/ft^3	22.0%	98.0 lb/ft^3

Permeability(c) (USBR Earth Manual, E-13)

	Compactive Effort	Permeability at Loading		
		50 psi	100 psi	200 psi
Low	6,200 ft-lb/ft^3	15.5 ft/yr	5.5 ft/yr	1.7 ft/yr
Moderate	12,375 ft-lb/ft^3	7.0 ft/yr	1.4 ft/yr	0.8 ft/yr
High	56,250 ft-lb/ft^3	1.1 ft/yr	0.6 ft/yr	0.08 ft/yr

(a) Sample 1-B taken from Paraho semiworks plant at Anvil Points, Colorado

(b) Average of two values

(c) Minus 1-1/2 inch fraction

(d) Lower numbers have been reported by others on similar materials saturated flow. In order to estimate saturated flow velocities, assume a hydraulic head gradient of unity and steady state saturated flow in homogeneous spent shale. Darcian velocity (flux) becomes then equal to the hydraulic conductivity. Assuming that a moderate compactive effort is applied to the spent shale, the Darcian velocity, under the above assumptions, would be 0.4 meter (1.4 feet) per year (see Table 8-1). The spatial inhomogeneity of the permeability of the processed shale pile due to the deposition of other solid wastes with the processed shale is not considered here, but may significantly affect flow within the pile. Dividing the Darcian velocity by the volumetric water content (10 percent), the real velocity of water would be 426 cm (14 feet) per year. In other words, for the full 150-meter (500-foot) depth of the spent shale pile, saturated movement of water (and pollutants) from the surface to the interface with the underlying Uinta Formation would require about 36 years. Pollutant movement during unsaturated flow would take a correspondingly greater time.

The spent shale pile will be built up in layers and compacted by trucks rolling over the surface. Water movement through the pile may be affected by layering, i.e., by the so-called interface effect. In stratified soils, for example, it is known that water content values increase in the vicinity of the interfaces between soils of different texture. Lateral flow may occur above the interface until sufficient hydraulic gradient develops to permit vertical flow. An interface effect could also occur between the spent shale pile and underlying Uinta sandstones. However, because of the low hydraulic conductivity values expected within the spent shale pile, the effect of layering on the movement of water and pollutants in the piles will probably be minimal. An exception may be in the region where the toe of the pile thins out, near the retention dam.

MOBILITY OF POLLUTANTS

Pollutant sources can be divided into four general categories: (1) major inorganic ions (or macroinorganics), (2) inorganic trace elements, (3) organics, and (4) microorganisms. Pollutant mobility underlying three principal source areas—(1) spent shale disposal area, (2) the process area, and (3) retention dams and reservoirs—will be considered. Characteristics of the vadose zone beneath each of these areas were discussed in the previous paragraphs.

Spent Shale Disposal Area

The disposal area in Southam Canyon will include sanitary landfills for the elimination of solid wastes, and the spent shale pile. Initially, a landfill will be prepared in a side canyon. Eventually this landfill and others will be incorporated within the spent shale pile (see Figure 8-1).

The spent shale pile represents the largest potential source of groundwater contamination on the tracts. In fact, the pile constitutes not only a source but also a part of the vadose zone. Sources within the spent shale fill include macroconstituents and microconstituents present in the residue from oil shale retorting. Of particular concern is that such residues also contain between 0.02 and 0.2 percent benzene-soluble organics, some of which may be carcinogenic (see Section 3; Schmidt-Collerus, 1976). Also deposited within the spent shale area are the solid wastes. Included in the solid wastes are construction materials, trash and garbage, spent catalysts, filter cakes, and elemental sulfur slurry. Waste water will be used to wet down the spent shale during waste disposal, contributing bacteria and viruses. Sewage sludge will be added to soils in vegetative trenches which will be constructed on top of the shale pile. Sludge contributes high concentrations of heavy metals.

Mobility in the fabricated vadose zone within the spent shale pile is discussed separately from mobility in the underlying vadose region.

Mobility in the Spent Shale Pile—

The mobility of inorganic, organic, and microbial pollutants within the upper vadose region will be affected by physical-chemical reactions within the porous matrix of the spent shale and by changes in the hydraulic properties of the media.

Physical-chemical reactions—Specific physical-chemical reactions affecting the mobility of pollutants in general are reviewed by Todd et al. (1976) and by Runnells (1976). Runnells (1976) lists 11 such reactions: dilution, buffering of pH, precipitation by reaction of wastes with indigenous waters or solids, precipitation due to hydrolysis, removal due to oxidation or reduction, mechanical infiltration, volatilization and loss as a gas, biological assimilation or degradation, radioactive decay, membrane filtration, and sorption.

Macroinorganics—Table 8-2 indicates the concentration of macroinorganics present in leachate from processed oil shale. The initial sample contained about 140,000 mg/l of TDS, with a high concentration of sodium and sulfate. This concentration is assumed, for this discussion, to represent the undiluted concentration of solute within the porous matrix.

Should leachate occur, the mobility of the macroconstituents in the matrix solution is difficult to predict because of the excessive concentration of total salts. According to Fuller (1977), "no general statement about ion concentration and attenuation can be made because the subject is too complex and very little work has been done with the chemistry of high concentration-multiple ion systems." Studies by soil scientists show that as the soil solution becomes more concentrated, the salt species likely to precipitate first are the alkaline-earth carbonates, such as $CaCO_3$ (calcite, aragonite, or vaterite), $MgCO_3$, and (Ca, Mg) CO_3 (McNeil, 1974). Precipitation-solution of $CaCO_3$ may be predicted knowing the pH and the activities of constituents in solution. The activity, in turn, may be determined from the Debye-Huckel equation. As pointed out by Back and Hanshaw (1965), the Debye-Huckel equation may be used for waters with salt contents up to about 8,000 mg/l. In other words, the Debye-Huckel relationship cannot be used to determine the extent of $CaCO_3$ precipitation in the initial solution shown in Table 8-2. For lower concentrations, it may be possible to use a method developed by Bower et al. (1965) to determine the tendency of $CaCO_3$ to precipitate.

TABLE 8-2. EXPERIMENTAL RESULTS OF THE PERCOLATION EXPERIMENT CONDUCTED ON TOSCO SPENT OIL SHALE RETORTING RESIDUE

Volume of leachate sample (ml)	Total volume of leachate (ml)	Conductance of sample (μmhos/cm at 25° C)	Concentration (mg/l) of sample					
			Na^+	Ca^{++}	Mg^{++}	$SO_4^=$	Cl^-	HCO_3^-
254	254	78,100	35,200	3,150	4,720	90,000	3,080	7,021
340	594	61,600	26,700	2,145	3,725	70,000	1,900	—
316	910	43,800	14,900	1,560	2,650	42,500	913	—
150	1,060	25,100	6,900	900	1,450	21,500	370	—
260	1,320	13,550	2,530	560	500	8,200	205	—
125	1,445	9,200	1,210	569	579	5,900	138	—
155	1,600	7,350	735	585	468	4,520	138	—
250	1,850	6,825	502	609	536	4,450	80	—
650	2,500	5,700	—	—	—	—	—	—
650	3,150	4,800	—	—	—	—	—	—
650	3,800	4,250	—	—	—	—	—	—
760	4,560	3,850	—	—	—	—	—	—
	∞[a]	1,800	86	64	118	740	11	—

[a] Extrapolated values that are probably accurate to within ±6 percent

Next to $CaCO_3$, the precipitation of gypsum ($CaSO_4$) is important as a process for removing salts from solution. It may be possible to predict the precipitation of gypsum using Debye-Huckel theory (Dutt et al., 1972). However, as pointed out for the case of $CaCO_3$, the leachate values shown in Table 8-1 exceed the TDS limits for which the theory is valid.

Although it is not possible to quantify the changes in solute composition within a spent shale pile, a qualitative estimate is possible. In particular, the dominance of sodium and sulfate indicates that soluble sodium sulfate will become dominant in the leachate after calcite and gypsum have precipitated (see Section 3). The high solubility of these constituents in leaching waters will probably result in insignificant attenuation. Thus the major ionic species are expected to be very mobile should leachate occur in the processed shale pile.

Sulfate may have an effect on heavy metal mobility if reducing conditions promote the formation of sulfides. The movement of ammonia and nitrate produced in solid waste cells buried within the disposal pile will be affected by oxidation reduction conditions. Thus ammonia and nitrate will be generated if conditions are favorable for the associated microorganisms, such as plentiful oxygen and favorable pH, and salinity. Similarly, denitrification will occur if anaerobic conditions occur (e.g., in perched water tables) together with an organic food supply. It appears that the extreme salinity of the leachate may limit the activity of microorganisms.

Of the other mechanisms for physical-chemical attenuation of major inorganic constituents besides precipitation, only sorption by organics may be of importance. The extent to which surfaces within the spent shale are reactive and thus can act to reduce the high concentrations of cations in the leachate is not well understood. Certain organic compounds, however, are known to possess a larger cation exchange capacity than clays.

Trace elements—Trace elements of concern in the retorted shale include iron, nickel, molybdenum, selenium, strontium, rubidium, manganese, chromium, arsenic, lead, mercury, and cerium. Results of leaching studies by Metcalf and Eddy (1975) indicate that arsenic, strontium, selenium, fluoride, and zinc may be present in excessive concentrations. Also, high levels of copper, nickel, cobalt, and molybdenum occur in spent catalysts.

Fuller (1977) lists 10 general factors as important in migration of heavy metals: hydrogen ion activity (pH), oxidation reduction, particle size distribution of soils (surface area), pore size distribution, lime, organic matter, concentration of ions or salts, certain hydrous oxides, climate (weathering), and aerobic and anaerobic conditions. In controlled laboratory experiments, Korte et al. (1977) found that soil properties dominant in influencing trace contaminant mobility are soil texture and surface area, percentage of free oxides (i.e., oxides of iron existing as discrete patches or coatings on soil minerals) and pH. Although Table 8-1 shows some of the physical properties of Paraho-processed shale, data on surface area unfortunately are not available. Inferring from the particle size information, however, it appears that corresponding to the low clay content the active surface is probably small. Data on the percentage of free oxides also are not available at this time. The pH of spent oil shale is on the alkaline side (about pH 10).

The figures developed by Korte et al. (1977) on the relative mobility of cations in the 10 most prominant soils orders in the United States are used as a first estimate of the mobility of heavy metals in the processed shale. These figures are reproduced as Figures 8-2 and 8-3.

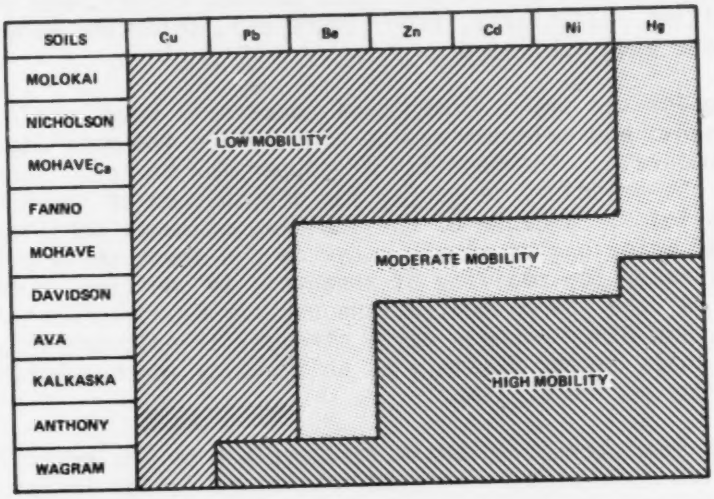


Figure 8-2. Mobility of copper, lead, beryllium, zinc, cadmium, nickel, and mercury (Korte et al., 1977).

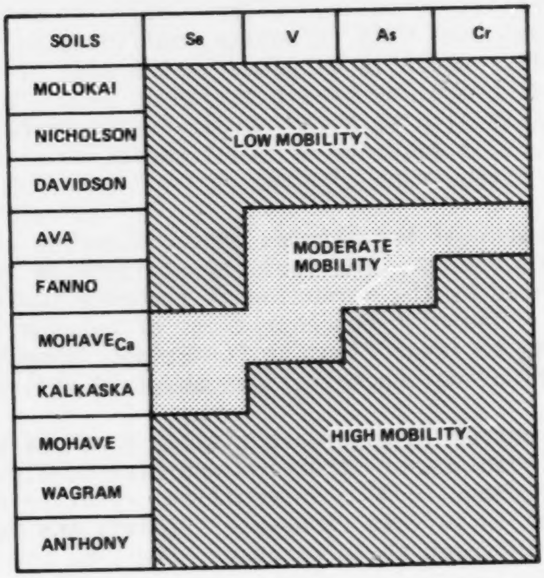


Figure 8-3. Mobility of selenium, vanadium, arsenic, and chromium (Korte et al., 1977).

Characteristics of the soils used in the study by Korte et al. (1977) are described in Table 8-3. Comparing soils of Table 8-3 with spent shale on the Uinta tracts, it appears that the Mohave soil is the closest in properties. Mohave is of the Order Aridisol as, for example, are the soils on the tracts. As a first approximation, the mobility of trace elements in the spent shale is assumed to be similar to Mohave sandy loam. From Figure 8-2, copper and lead have low mobilities; beryllium, zinc, cadium, nickel, and mercury have moderate mobilities. Similarly, from Figure 8-3, selenium, vanadium, arsenic, and chromium have high mobilities.

Summarizing for the trace elements of concern in spent shale leachate, the mobility of arsenic and selenium may be high, while the mobility of zinc and nickel may be moderate. The mobility of copper may be low. According to Fuller (1977), the principal mechanism for attenuation of arsenic is adsorption by soil colloids. Because of the low clay content, mobility of arsenic may be high. If waterlogging should occur in the spent shale pile, reducing conditions will favor the mobility of arsenic. In addition, according to Fuller (1977), "At the low concentrations usually found in waste waters, landfill leachates, and other aqueous waste streams, arsenic probably will not precipitate in soils except possibly as an impurity in phosphorus compounds formed over a long period of time."

The complex chemistry of selenium is described by Fuller (1977). The behavior of selenium is closely related to that of sulfur in acid formation and other properties. Based on experimental studies at the University of Arizona, Fuller concluded that other factors being equal, selenium is less mobile in acidic than in neutral or alkaline soils.

Regarding the mobility of zinc, Fuller (1977) indicates that Zn^{+2} forms slowly soluble precipitates with carbonate, sulfides, silicate, and phosphate ions. Elemental sulfur which is disposed in the pile in slurry form may be converted to sulfide, promoting precipitation of zinc (and other cationic heavy metals). Zinc is also strongly sorbed on the exchange complex of soil. Because of the low cation exchange of spent shale, this factor may not be of great importance in attenuation of zinc.

Unlike other members of the halogen group, fluorine compounds tend to be rather insoluble (Hem, 1970). The mobility of fluoride in spent oil shale leachate may be limited by the formation of fluorite (CaF_2), with a solubility product of $10^{-10.57}$. The high concentrations of calcium in leachate (see Table 8-2) would tend to favor fluorite formation, in spite of common ion effects. Even so, fluoride concentrations about 10 mg/l may be expected.

Reactions of strontium in water are similar to those of calcium. Strontianite, formed by the reaction of strontium and bicarbonate, is slightly less soluble than calcite (Hem, 1970). In addition, relatively insoluble strontium sulfate may be formed in sulfate rich waters (Davis and DeWiest, 1966). Both reactions may occur in spent shale leachate, limiting the mobility of strontium.

Copper appears to be strongly complexed to organic matter (Fuller, 1977); consequently, soluble and mobile copper-organic chelates may form in the spent

TABLE 8-3. CHARACTERISTICS OF THE SOILS[a]

Soil	Order	pH	CEC[b] (me/100 g)	EC[c] (μmhos/cm)	Surface area (m^2/g)	Free iron oxides (percent)	Total Mn (ppm)	Sand (percent)	Silt (percent)	Clay (percent)	Texture class	Predominant clay minerals[d]
Wagram (N. Carolina)	Utisol	4.2	2	225	8.0	0.6	50	88	8	4	loamy sand	Kaolinite, chlorite
Ava (Illinois)	Alfisol	4.5	19	157	61.5	4.0	360	10	60	31	silty clay loam	Vermiculite, kaolinite
Kalkaska (Michigan)	Spodosol	4.7	10	237	8.9	1.8	80	91	4	5	sand	Chlorite, kaolinite
Davidson (N. Carolina)	Ultisol	6.2	9	169	51.3	17	4,100	19	20	61	clay	Kaolinite
Molokai (Hawaii)	Oxisol	6.2	14	1,262	67.3	23	7,400	23	25	52	clay	Kaolinite, gibbsite
Chalmers (Indiana)	Mollisol	6.6	26	288	125.6	3.1	330	7	58	35	silty clay loam	Montmorillonite, vermiculite
Nicholson (Kentucky)	Alfisol	6.7	37	176	120.5	5.6	950	3	47	49	silty clay	Vermiculite
Fanno (Arizona)	Alfisol	7.0	33	392	122.1	3.7	280	35	19	46	clay	Montmorillonite, mica
Mohave (Arizona)	Aridisol	7.3	10	615	38.3	1.7	825	52	37	11	sandy loam	Mica, kaolinite
Mohave (Arizona)	Aridisol	7.8	12	510	127.5	2.5	770	32	28	40	clay loam	Mica, montmorillonite
Anthony (Arizona)	Entisol	7.8	6	328	19.8	1.8	275	71	14	15	sandy loam	Montmorillonite, mica

[a] From Korte et al., 1977

[b] Cation Exchange Capacity

[c] Electrical Conductivity

[d] Listed in order of importance

shale pile. The formation of hydrous oxides of manganese and iron provides the main control in the immobilization of copper. No data are available on hydrous oxides in spent shale. Hem (1970) reports that copper solubility is generally lower in reducing systems than in oxidizing systems, particularly if reduced sulfur species are present. Reducing or anaerobic conditions could exist if saturation develops in fissures or cracks above claystone beds. Reduction of sulfate, present in spent shale leachate, would then lead to precipitation of copper (as well as iron, zinc, cadmium, lead, and mercury [Fuller, 1977]).

Both nickel and cobalt are strongly adsorbed by iron and manganese oxides (Hem, 1970). The significance of this effect in immobilizing cobalt and nickel in spent shale cannot be defined at this time. The low solubility of cobalt carbonate may be an important factor in limiting cobalt concentrations in the disposal pile, particularly in light of the high bicarbonate concentrations in leachate.

According to Hem (1970) there are no effective solubility controls over molybdenum concentrations in water. Consequently, the mobility of the anionic form, molybdate, will probably be high in the waste pile. This mobility will be enhanced by the high pH of the processed shale leachate.

The potential for mobility of boron within the spent shale disposal area is unclear. In soils the principal limitation upon boron mobility is sorption on clay surfaces. This may not be important in the processed shale pile. Boron may also be tied up with organics associated with the processed shale and thus be attenuated. Other mechanisms of boron sorption include interaction with oxidized and hydrous forms of iron and aluminum, with magnesium hydroxy coatings of ferromagnesium minerals, and with the interlattice structures of micateous minerals (Soil Science Society of America et al., 1977; Hem, 1970).

The possibility of chelation of trace elements with organics present in oil shale and subsequent transport was discussed by Schmidt-Collerus (1974): "A... potential effect on the...environment may arise from the depletion of the soil of important trace elements due to complex bonding of these elements onto specific organic compounds (aromatic or polyaromatic)...Furthermore, solubilization and transporation in colloidal form of these organic compounds in surface and groundwaters may have long-range chronic effects (of as yet unknown nature) on the aquatic ecology in creeks, rivers, ponds, and on the purity of potable water."

The properties of leachate within the spent shale pile will be altered when exposed to air, e.g., when seeping out of the face of the pile near Southam Canyon retention dam. The pH of leachate emerging from the shale pile is between 8 and 9. Within a few weeks, the color changes to blue and the pH to 2 to 3 (Metcalf and Eddy, 1975). The pH change is attributable to the oxidation of sulfides and polythionates. A major effect of reducing the pH to such low values is that the attenuation of trace elements, except selenium, chromium, and arsenic, tends to decrease, i.e., mobility accelerates (Fuller, 1977). Consequently, surface water entering the Southam Canyon retention damsite from the spoil piles may have elevated concentrations of heavy metals.

Organics—Spent oil shales may contain two to three orders of magnitude greater concentrations of benzene-soluble organics than native soils (Schmidt-Collerus et al., 1976). Carcinogenic organics are of particular concern since leachate from the spent shale pile may contain from three to four times the concentration of polycyclic aromatic hydrocarbons found in native groundwater. When the amount of spent shale is taken into consideration, the scale of the potential problem (of organics) is enormous. At full 100,000 barrels per day production, the operation could produce 1.8 million tons of carbonaceous material and over 100,000 tons of benzene-soluble organics per year. If process water is used to moisten the shale, up to 400,000 tons of benzene-soluble compounds could be released per year.

Organics are also added during wetting of the spent shale pile with waste water from the secondary treatment plant, oily waste water (including oils and grease, phenols, etc.), and process water.

A problem in specifying the mobility of specific organics is that quantitative studies have only recently been reported. One problem is that analytical procedures to identify organics are still being developed. Research is needed to improve capabilities to analyze samples comprehensively so that significance of trace organics in the environment can be determined (Donaldson, 1977). Recently, Leenheer and Huffman (1976) described the development of the dissolved organic carbon (DOC) technique for fractionating organics into hydrophobic and hydrophilic components using macroreticular resins. The technique was applied to several natural waters. This technique has advantages over other methods for concentrating organics, such as activated carbon. For example, Robertson, Touissant, and Jorque (1974) reported that only 10 percent of organics present in groundwater beneath a landfill in Oklahoma were identified using carbon adsorption followed by carbon chloroform and carbon alcohol extraction.

Because of limited information on the attenuation of organics in a porous matrix such as spent shale, only general, qualitative estimates of mobility can be presented at this time. Sorption may be an important factor in attenuation. It is known, for example, that polychlorinated biphenols (PCBs) tend to be adsorbed strongly by soils and also are very insoluble in water (Robertson, Toussaint, and Jorque, 1974). Leenheer and Huffman (1976) indicate that both hydrophobic and hydrophilic organics may be sorbed by sediment.

Adsorption may be a factor in the spent shale because of the fairly high carbon content: TOSCO II shale residue contains 4.5 percent by weight organic carbon and Paraho residue contains 3 percent (Yen, 1976). Schmidt-Collerus (1974) indicated: "Carbonaceous spent shale from commercial oil shale operations may be present as finely divided or coarse particles with relatively large surface area...The larger surface area and the possible presence of active sites on the residual carbon of the ash particles can provide strong adsorption and/or chemisorption forces..." Brown (1977) noted a marked attenuation of fluorocarbons during miscible displacement studies using coal.

The pH may also be a factor in mobility of organics. For example, Leenheer and Huffman (1976) observed the formation of an organic precipitate upon acidification of a groundwater sample from an oil shale area near Rock Springs, Wyoming. Raising the pH dissolved the precipitate. Since the pH within the spent shale pile will be above 7.0, the precipitation of organics may not be a factor. However, leachate seeping from the toe of the spent shale pile will gradually change from high pH values to values as low as 2.0 (Metcalf and Eddy, 1975). Organics could precipitate out at these low pH values.

Schmidt-Collerus (1974) states: "Solubilization of POMs (polycondensed organic materials) is also enhanced by the presence of various inorganic salts which may play an important role in the transportation of PAH (polycondensed aromatic hydrocarbons) compounds by saline water or from soils (rich in soluble salts) by runoff water or seepage water." Because of the great salt content of spent shale leachate, considerable movement of polycyclic aromatic compounds would be expected. Some notion of the mobility of organics in spent shale is apparent in results from leaching studies reported by Metcalf and Eddy (1975) shown in Tables 8-4 and 8-5. Samples of processed shale were moistened with two dilutions of "foul water" in ratios of 4:1 and 2.5:1. The organics leached were expressed as TOC (total organic carbon). The total TOC leached averaged 55.5 percent for the 4:1 dilution and 53 percent for the 2.5:1 dilution.

TABLE 8-4. LEACHING OF SOLUBLE MATERIAL FROM PROCESSED SHALE MOISTURIZED WITH A 4:1 DILUTION OF FOUL WATER[a]

Constituent	Shale sample size, grams	
	500	1,000
Total water applied, ml	1,250	2,500
Total leachate recovered, ml	1,100	2,245
Water recovery, percent	88.0	89.8
TOC leached, mg	99.8	226.9
TOC leached, kg/tonne (lb/ton) raw shale	0.165 (0.33)	0.185 (0.37)
TOC added in water, kg/tonne (lb/ton)	0.185 (0.37)	0.185 (0.37)
TOC in dry shale, kg/tonne (lb/ton)	0.129 (0.26)	0.129 (0.26)
Total water soluble TOC, kg/tonne (lb/ton)	0.315 (0.63)	0.315 (0.63)
TOC leached, percent	52.4	58.7

[a] From Metcalf and Eddy, 1975

TABLE 8-5. LEACHING OF SOLUBLE MATERIAL FROM PROCESSED SHALE MOISTURIZED WITH A 2.5:1 DILUTION OF FOUL WATER[a]

Constituent	Shale sample size, grams	
	500	1,000
Total water applied, ml	1,250	2,500
Total water recovered, ml	1,100	2,285
Water recovery, percent	88.8	91.4
TOC leached, mg	119.4	314.4
TOC leached, kg/tonne (lb/ton)	0.179 (0.39)	0.259 (0.52)
TOC added in water, kg/tonne (lb/ton)	0.299 (0.60)	0.299 (0.60)
TOC in dry shale, kg/tonne (lb/ton)	0.129 (0.26)	0.129 (0.26)
Total water soluble TOC, kg/tonne (lb/ton)	0.429 (0.86)	0.429 (0.86)
TOC leached, percent	45.3	60.5

[a] From Metcalf and Eddy, 1975

Discussing the air pollution aspects of waste dumps, Schmidt-Collerus (1974) speculates on the loss of volatile hydrocarbons by surface evaporation and self-heating. The possibility is also raised of auto-oxidation releasing carbon dioxide, carbon monoxide, sulfur dioxide, and volatile hydrocarbons such as alkanes and olefins. No data are available on the overall loss of organics by volatilization and/or oxidation.

Finally, as an attenuation mechanism, the effect of microorganisms on organics should be mentioned. In particular, biodegradable organics will be decomposed by microorganisms rendering potentially harmful constituents into gases. Davis (1956) reports that microbiologists have observed the utilization of hydrocarbons by certain bacteria, actinomycetes, filamentous fungi, and yeasts. In general, however, hydrocarbons are not as readily decomposed as carbohydrates, proteins, or fats. Furthermore, the cyclic hydrocarbons are less susceptible to microbial decomposition than are the aliphatic hydrocarbons. Quantitative estimates of biodegradation of organics in spent shale are not available.

Microorganisms—Microorganisms (including viruses) will be added during wetting down of the spent shale pile with secondary treated waste waters, and possibly with solid wastes. According to Gilbert et al. (1976), bacteria are removed at the soil surface by filtration, sedimentation, and adsorption.

Other factors listed by Gilbert et al. (1976) as important in attenuating bacteria and viruses are salt concentration, pH, organic matter, soil composition, infiltration rates, and climatic conditions. Survival and movement of microorganisms within a soil relate to soil moisture content, temperature, pH, nutrient availability, and antagonisms.

Undoubtedly, the above mechanisms will limit the migration of bacteria and viruses to within a short vertical distance of the spoil pile surface. There may be a problem during the initial stages of the spoil pile, during which microorganisms could cross into the lower vadose zone. Another possible factor in promoting the particular movement of viruses is snow or rainfall on the surface. Lance, Gerba, and Melnick (1976) observe the desorption and migration of viruses in soil columns following the application of deionized water. Resorption occurred further down the column. Applying these results to the spent oil shale pile means that viruses may become desorbed following the infiltration of snowmelt. When the spoil pile is of limited thickness, such as during initial buildup, viruses could migrate through fissures into the lower vadose zone. Later, with increased thickness of the spent shale pile, the viruses would be resorbed with depth.

Effects on hydraulic properties—In areas receiving scanty rainfall, salts moving with the soil solution tend to accumulate in indurated layers within a short distance of the surface (McNeal, 1974). Soil layers with high concentrations of gypsum or carbonate minerals may develop. Total concentrations of salt may amount to 10 to 50 percent of the soil mass (McNeal, 1974). Such layers restrict vertical movement of water and hence mobility of pollutants.

This condition is possible in the spent shale pile, which is excessively high in total salts. Calcite and gypsum salts may be precipitated from the soil solution, and form an indurated layer, reducing the mobility of pollutants.

Quirk and Schofield (1955) have shown a relationship of total salt concentration of the soil solution, hydraulic conductivity, and exchangeable sodium percent (ESP). Figure 8-4, from McNeal (1974), illustrates that for a given ESP, the hydraulic conductivity increases with total salt content. This relationship will be estimated using salt concentration values for leachate from Table 8-2, together with estimates of ESP to approximate the relationship of salt content and ESP on the hydraulic conductivity of spent shale (and hence mobility of pollutants).

The following analysis assumes that a response of spent shale to salt vis-à-vis hydraulic conductivity is similar to that for Pachappa sandy loam (Figure 8-4).

Exchangeable sodium percentages (ESP) of a soil may be calculated from the relationship (Richards, 1954):

$$\mathrm{ESP} = \frac{100\ (-0.0126 + 0.01475\ \mathrm{SAR})}{1 + (-0.0126 + 0.01475\ \mathrm{SAR})} ,$$

where SAR = sodium adsorption ratio

$$= \frac{Na^+}{(Ca^{++} + Mg^{++})/2}$$

(all units in milliequivalents per liter [meq/l]).

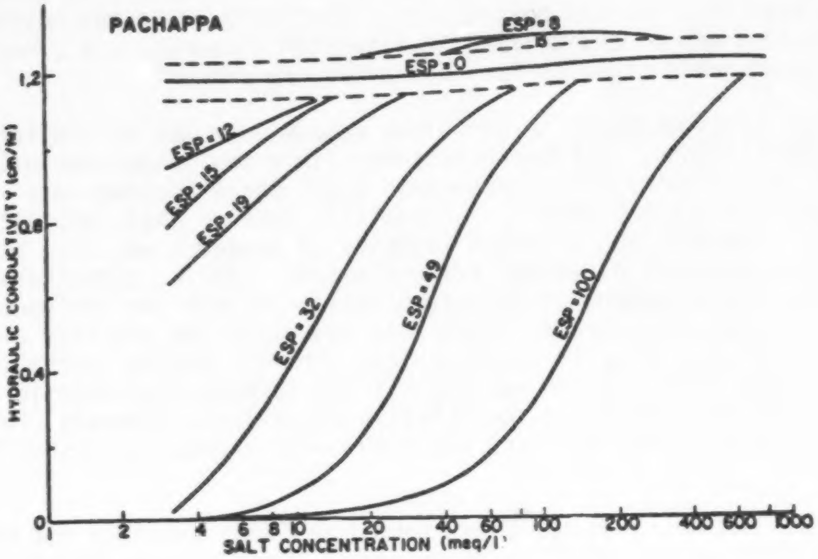


Figure 8-4. Hydraulic conductivity of Pachappa sandy loam as related to salt concentration and exchangeable sodium percentage (McNeal, 1974).

For the initial leachate of Table 8-2, SAR = 92.6 and ESP = 57.50, the total salt concentration is 4,080 meq/l. From Figure 8-4, the hydraulic value (for Pachappa sandy loam) would be maximum for a salt content of about 200 meq/l, corresponding to an ESP of 57.5. Consequently, for the high salt content observed in initial leachate, one would expect the flux to be high. With later volumes of leachate, precipitation of calcium and magnesium carbonate would modify SAR and ESP values. For example, using the values of Table 8-2 for the final aliquot of leachate, the SAR = 1.5, the ESP = 0.90, and total salt is 33 meq/l. The latter value approaches the horizontal line on Figure 8-4, indicating that the maximum hydraulic conductivity obtains for all values of total salt. In other words, flux (and pollutant mobility) remains high at both high and low total salt contents.

"Indigenous" Vadose Zone Pollutant Mobility—

Assuming that pollutants migrate into the indigenous vadose zone from the overlying spent shale pile, further downward movement will occur through fractures and fissures, rather than through a porous matrix. Because of the nonreactive nature of the Uinta sandstones, attenuation of pollutants by exchange reactions will be minimal. (The possibility of reactions on clay beds within the Uinta sandstones is uncertain.) Attenuation of macroconstituents in spent shale leachate will probably depend upon precipitation reactions, such as the formation of calcite or gypsum. In the presence of bacteria and organic matter, sulfates may be reduced to sulfides (Hem, 1970). Since the solubility of the sulfides of most metals is low, metals in spent shale leachate may be precipitated out. This effect may occur if biodegradable organics from the overlying shale pile migrate into the Uinta formation; however, no quantitative data are available on this possibility. Similarly, nitrates moving into the Uinta formation may be denitrified in saturated fissures, e.g., near clay lenses, if biodegradable organics (and bacteria) are present.

The fate of trace elements in the Uinta vadose zone may be similar to that of macroconstituents. Surface reactions within the sandstones will be minimal. Reactions with organics present in spent shale leachate may promote chelation of trace elements, and possibly enhance their mobility (Fuller, 1977). However, the exchange capacity of organics may also be great enough to inhibit movement of sorbed trace elements. Again, quantitative data are lacking. Development of saturated regions within the indigenous vadose zone will promote anaerobic conditions and favor the mobility of heavy metals, unless insoluble metallic sulfides are formed. Another possible mechanism affecting trace element movement is the formation of organic acids, which lower the pH and accelerate the mobility of cationic elements (Fuller, 1977). Finally, adsorptive reactions may occur with hydrous oxides of Fe^{++}, Mn^{++}, and Al^{+++}.

Adsorptive reactions with the Uinta sandstones will probably not be significant in limiting the mobility of organics. Possibly the formation of organic acids will lead to the precipitation of certain organic compounds.

Bacteria may be filtered out by the fine fissures within the Uinta sandstones, but free movement will occur through larger cracks. Similarly, virus removal by sorption will not be significant. Changes in pH may be a factor in virus mobility, however.

Process Area

Possible pollutants in the process area are summarized in Table 8-6. Inorganics will be present in high TDS waste water. Ammonia will also be present in tankage. Organics will be included in crude shale oil, refined shale oil, naphtha, fuel oil, diesel fuel, and oil and grease. Microorganisms will be found in the waste water holding pond.

Movement of some pollutants will occur across the shallow soil (except for the holding pond reservoir) into the underlying Uinta sandstones. Properties of the soils of the area are reported in Table 8-7. These soils are classified as sandy loams. Note the low cation exchange capacity (CEC), averaging 9.14 meq/100 g. According to Buckman and Brady (1969), the CEC of soils in semiarid regions is commonly between 20 and 26 meq/100 g, but may sometimes exhibit a much wider range.

TABLE 8-6. POSSIBLE PROCESS AREA POLLUTANTS[a]

Tankage[b,c]	Amount	
	Cubic meters (thousands)	Barrels (thousands)
Crude shale oil	240.0	1,500.0
Refined shale oil	176.0	1,100.0
Naphtha	56.0	350.0
High TDS waste water	35.2	220.0
Fuel oil	11.2	70.0
Ammonia	8.0	50.0
Diesel fuel	5.6	35.0
Waste water holding pond	Amount, mg/l	
	Maximum	Minimum
Total dissolved solids	800[d]	200
Oil and grease	100	50
Phenol	85	45
Ammonia	30	50
pH	9.25	7.9

[a] from WRSP, 1976a

[b] Includes butane, liquid nitrogen, and shale oil pour-point depressant in addition to products listed

[c] Process facilities also contain all tankage products in lesser amounts

[d] TDS may be more than amount shown

TABLE 8-7. CHARACTERISTICS OF SOILS ON OIL SHALE TRACTS[a]

Sample	Depth (cm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Na^{+} (ppm)	EC x 10^3	TSS	CEC	Sand (percent)	Silt (percent)	Clay (percent)
D-1	0-15	80	3.5	20	0.52	364	9.50	57.0	35.0	8.0
D-1	15-25	63	3.0	29	0.43	301	10.98	56.6	35.4	8.0
D-1	25-30	48	3.0	84	0.64	448	10.88	58.0	35.0	7.0
D-1	30-35	44	2.9	132	1.02	714	11.30	55.5	36.5	8.0
D-2	0-10	62	8.1	44	0.94	653	5.45	64.0	28.0	8.0
D-2	10-20	44	3.1	30	0.44	308	7.18	69.0	25.0	6.0
D-2	20-30	50	2.0	36	0.43	301	9.45	53.0	38.0	4.0
D-2	30-40	38	1.8	37	0.36	252	10.88	58.0	41.0	1.0
D-2	40-50	45	1.0	37	0.29	203	9.03	65.5	32.5	2.0
D-2	50-60	99	1.5	45	0.35	245	9.13	66.0	30.0	4.0
D-2	60-70	40	2.2	50	0.42	294	9.03	69.0	27.0	4.0
D-2	70-80	31	2.2	46	0.37	259	7.95	68.0	28.0	4.0
D-3	0-10	75	11.4	34	0.80	560	5.65	71.0	23.0	6.0
D-3	10-20	60	4.1	56	0.61	427	8.93	69.0	27.0	4.0
D-3	20-30	50	2.3	61	0.50	350	9.89	68.5	29.5	2.0

[a] Samples collected during 1977 surveys for General Electric—TEMPO

Because of the thinness of the soil mantle and the low CEC, it appears that attenuation of inorganic pollutants by exchange reactions may not be very significant. High TDS water containing calcium, magnesium, sulfate, and bicarbonate may lose some salts due to the precipitation of calcite and gypsum, as described above. A perched water table might develop at the interface between the oil and underlying Uinta sandstones, promoting sulfide formation (if sulfates are present) and the consequent precipitation of metals.

High salinity waste water will favor the movement of organics in soils (Schmidt-Collerus, 1974). Soil microorganisms may be capable of attenuating organics by biodegradation, particularly if the soils are well aerated and if the salinity is reduced.

Filtration of bacteria may not be too effective because of the coarse texture of the soils. Similarly, significant attenuation of viruses in waste water by sorption on the exchange complex may not occur.

Movement and attenuation of pollutants in the Uinta Formation underlying the process area will be governed by mechanisms described above for the spent shale disposal area.

Retention Dams

Retention dams will be constructed downstream of the Phase II spent shale pile, the sanitary landfill, and the Phase III and Phase IV spent shale pile (the Southam Canyon retention dam). These dams will be used to collect and store leachate as well as surface runoff. Collected water will be used for irrigation of vegetation or for dust control. Alluvium will be stripped from the Southam Canyon dam site, and a liner will be installed on the reservoir area to minimize leakage. To date (August 1977), a liner material has not been selected (R.C. Madsen, private communication, 1977).

Leachate flowing out of the spent shale piles into the retention dams may contain excessive concentrations of salt (see Table 8-1), the pH may be reduced to values as low as 2 or 3 (Metcalf and Eddy, 1975), and levels of trace elements may increase accordingly. Leachate entering the calcareous soils would be expected to increase in pH, thus affecting trace metal mobility. In addition, "Polycyclic aromatic compounds can apparently be leached from the carbonaceous shale by water to a considerable extent in the presence of water-soluble inorganic salts," (Schmidt-Collerus, 1974). Similarly, surface runoff from the pile may contain high levels of salt and organics.

Seepage into the vadose zone underlying the Southam Canyon retention dam site will occur if the lining fails. Downward flow in the Uinta sandstones will then occur through cracks or along bedding planes, as discussed above. Attenuation mechanisms will be similar to those discussed for the spent shale disposal area and the process area. In addition to such mechanisms, the possibility exists that precipitated salts (e.g., calcite and gypsum) may close off fissures, restricting downward flow. Movement of pollutants in the vadose zone underlying the Phase II retention dam site and the landfill site will also be governed by these mechanisms.

SUMMARY OF MOBILITY

The principal source of groundwater contamination on the oil shale tracts will be the spent shale pile, which also will constitute a fabricated vadose region overlying the indigenous vadose zone. Particular contaminants in the spent shale pile will include an extremely high salt concentration (possibly as high as 140,000 mg/l, TDS) and a high loading of organics. The mobility of salt will be limited mainly by precipitation reactions, which could remove calcium and magnesium carbonates, and gypsum. Some sorption on organics may occur. The mobility of organics will be enhanced by the high TDS, and leaching of both contaminants (organics and inorganics) will occur together. Organic concentrations may be diminished by precipitation at higher pH values, by surface reactions, by auto-oxidation, and by microbial decomposition. Trace metal mobility will be affected by pH, complexing with organics, sorption on organics, precipitation as sulfides, etc. Microorganism levels probably will be limited by the high TDS.

Movement of water and pollutants in the fabricated vadose zone may be reduced by the presence of indurated layers formed by the precipitation of calcite and gypsum. Values of ESP, SAR, and TDS are such that the hydraulic conductivity will remain high.

Flux in the Uinta and underlying formations of the indigenous vadose zone will be restricted to fine cracks and fissures along bedding planes. Attenuation may be effected mainly by precipitation of salts, because sorptive effects will be limited (except possibly to organics).

The above discussion suggests that pollutants in spent shale leachate may be attenuated by a variety of physical-chemical processes. However, because of the initially high concentrations of the major inorganic constituents, the overall salinity level will remain high in leachate. In fact, if leachate were somehow to penetrate shallow alluvial aquifers, or the Bird's Nest Aquifer, serious quality impairment would occur.

It appears that movement of pollutants in the vadose zone underlying the spent shale tracts may be of importance only (1) when the spent shale pile is of minimum thickness, i.e., during the beginning of construction, and (2) when leachate from the toe of the pile accumulates in the Southam Canyon retention dam. The quality of the leachate in the latter situation will be particularly bad. Even for these conditions, it is not anticipated that pollutant movement in the indigenous vadose zone will be significant. An important point to remember is that the potentiometric level of water and pollutants above the Bird's Nest Aquifer must exceed the corresponding level within the aquifer and continuous hydraulic connection must exist before water movement will occur into the aquifer. Such a hydraulic continuum does not appear likely under present circumstances, but conceivably could be created by mining-induced subsidence.

HYDROGEOLOGIC MODIFICATION

Subsidence

One possible side effect of oil shale mining is land subsidence. When rock is removed from the subsurface, increased stress on the remaining rock is created by the removal of support. This stress is accommodated by strain on the walls and pillar of the cavity and by the formation of a compressive strain over the cavity. If the dimensions of the cavity are such that the top of the arch extends above the surface, the cavity will collapse until the strain arch is sufficiently reduced that the strain can be taken up within the rock. Outside of the arch (away from the cavity), extensional strain is created by the movement of rock into the cavity.

The planned mine at the U-a and U-b tracts is of the room-and-pillar type. The pillars are planned to be of sufficient dimensions to support the weight of the overburden. Thus rapid collapse of the mining cavity probably will not occur. Under these circumstances, some subsidence can be expected from compression of the mine pillars and the cavity roof. Rock mechanical data on the compressibility of the pillar rock are needed to evaluate the expected extent of subsidence.

Possible hydrogeologic effects of subsidence do not depend on the magnitude of subsidence so much as the resultant structural damage. Very ductile rocks can sustain considerable subsidence with little fracturing, while brittle rock may fracture extensively in response to slight subsidence. It is the cracking and fracturing which provide hydrogeologic connection.

The rocks above the Mahogany Zone are the marlstones of the Green River Formation and the sandstone of the Uinta Formation. The marlstone may be moderately ductile. Kerogen and clay would tend to increase plasticity, while calcium carbonate would decrease it. The Uinta Formation probably would be fairly brittle, but mudstone partings would tend to close fractures.

Although at present only partial extraction is planned, in the future, changing technological or economic conditions may encourage the practice of pillar extraction. This method involves the removal of pillars from a mining area when normal extraction is complete. Pillar extraction would certainly result in major subsidence and hydrogeologic modification.

Whatever the method, the location of subsidence would depend on the area mined out. If the mined area corresponds closely to the tract boundaries, as planned, the result would be a large area of compressive strain inside the tract boundaries. This strain could result in lowered transmissivity of aquifers in the area. The central area of the tracts could be under compressive strain or no strain at all. This area would experience maximum subsidence, but probably little structural damage.

The area just outside of the tract boundaries would experience extensional strain, very likely resulting in vertical cracking and fracturing. The extent of fracturing would depend on rock properties, extent of subsidence, rate of subsidence, and amount of curvature produced by subsidence. One effect of the tensional strain would be increased transmissivity within the strain zone.

The opening of vertical fractures would result in increased hydraulic interaction between the surface and aquifers, and between different aquifers. Since the tract boundaries intersect the White River in several places, it may be expected that, in the event of serious subsidence and fracturing, a connection between the White River and the Bird's Nest Aquifer would result. The effect of this connection would be increased leakage from the White River into the Bird's Nest Aquifer, since the aquifer level is below the river level. The downgradient flow in the aquifer would increase and some improvement in aquifer water quality would result, since the river water is of better quality. Discharge of the White River downstream of the leakage area would be decreased, although the magnitude of the change cannot be estimated with certainty.

If the subsidence fractures were of such scale as to extend through the Green River Formation to the mine zone, a serious mine drainage problem would be encountered. Water from both the Bird's Nest Aquifer and the White River would enter the mine. The dissolved solids content of water entering the mine would vary from more than 4,500 mg/l in the northeast corner of Tract U-b to less than 1,000 mg/l in areas where most of the leakage was contributed by the White River. The leakage might pick up some additional dissolved constituents while moving through the fractures or in the mine. If the leakage were of sufficient extent, it could result in substantially reduced flow in the aquifer downgradient of the mine, since most of the aquifer recharge in the region is from Evacuation Creek and the White River and could then be intercepted by the mine.

The possibility of subsidence-induced fracturing below the level of the mine does exist, but is very unlikely. Normally the solid rock beneath a mine is sufficient to accept the stresses created by mining without structural damage. Usually it is only when mining is commenced below an existing mine that these stresses cause damage. If deep fracturing did occur below the mine, groundwater from the Douglas Creek Member and lower aquifers could rise upward into the mine. Evidence exists that at the present time groundwater from lower aquifers is leaking upward into the Bird's Nest Aquifer below Evacuation Creek (see Section 6). If this is the case, this water would be intercepted by the mine. Subsidence-induced stress might further open fractures responsible for this leakage.

The major groundwater pollution problems associated with the possibility of mine drainage do not result from any undesirable characteristics of the mine water itself, but from the disposal of the water. It is proposed in the Detailed Development Plan (WRSP, 1976a) that this water will be used for dust control and wetting of the spent shale. If large quantities of mine water must be disposed, the amount spread on the spent shale pile may be sufficient to induce percolation through the pile and the production of high TDS leachate. This leachate could then degrade local groundwater.

White River Dam

Both the White River Shale Project and the State of Utah are encouraging the construction of a dam on the White River. The White River Shale Project favors a dam site near the northwest corner of Tract U-a (see Figure 2-3). Another dam site upstream of the tracts has also been proposed. At the present time, no dates have been set for dam construction.

The proposed dam would be 38 meters (125 feet) high. It would impound a reservoir with surface elevation approximately 1,524 meters (5,000 feet) in elevation. The lake would extend upstream well past Hell's Hole Canyon.

The existence of such a reservoir could alter the hydrogeology in several ways. Water filling the reservoir would slowly seep into the Uinta Formation through the reservoir walls. At present, the hydraulic gradient of the shallow alluvial aquifers on the tracts is northward, into the White River valley. For a period of time, at least, this gradient would be reversed as seepage from the reservoir penetrated southward. Since the regional structure rises to the south, the seepage from the reservoir probably would eventually fill all of the available alluvium and Uinta Formation above the relatively impermeable Green River Formation. At this time, the natural gradient would be reestablished. During the period of reverse gradient, any pollutants moving through the alluvium or Uinta Formation could tend to be stagnated south of the reservoir until the gradient returned to normal, when they would be flushed out.

The presence of a water table within the Uinta Formation would cause increased attenuation of any pollutants through dilution. However, the buoyant force of the water may open bedding planes within the Uinta Formation, thus increasing pollutant velocity and mobility. If pollutant flow is constrained by claystone beds within the Uinta Formation, the reservoir may increase the volume of pollutants able to enter the White River. Pollutants which would otherwise seep out of the Uinta Formation above the White River and precipitate would flow directly into the reservoir.

Evidence for downward leakage from the White River into the Bird's Nest Aquifer is discussed in Section 7. The raised head of the White River created by the reservoir would probably substantially increase the rate of leakage into the Bird's Nest Aquifer. This would improve the quality and flow of the aquifer.

If leakage of river water into the oil shale mine should occur due to subsidence-induced (or other) fracturing, the raised head created by the reservoir and the extended water table around the reservoir would undoubtedly greatly increase leakage into the mine. Finally, if subsidence does become a problem, the large additional weight of the reservoir above and adjacent to the mine would probably aggravate the problem.

SECTION 9

MOBILITY AND ATTENUATION OF POLLUTANTS IN THE SATURATED ZONE

ATTENUATION MECHANISMS

Knowledge of possible pollutant movement and concentration change is very important in the formulation of any groundwater monitoring system. Most of the basic data used to evaluate these factors in this section will be drawn from Section 5 (Hydrogeologic Framework). Elements covered will include chemical mechanisms of attenuation operating in both the saturated and the unsaturated regions. Thus much of the discussion of attenuation in Section 8 is applicable to this topic and will not be repeated in detail. Significant differences between the saturated and unsaturated zones and processes operating in only the saturated zone will be treated.

The primary influences on pollutants in the saturated zone are the physical and chemical characteristics of the aquifer. Parameters such as aquifer mineralogy, contact area, pH, and Eh are important. The peculiar solution cavity nature of the Bird's Nest Aquifer affects all of these parameters. Most of the cavities are large, typically 15 to 25 cm (5.9 to 9.8 inches) in diameter. The large scale of the individual "pores" of the aquifer greatly reduces the contact area of the aquifer minerals with the water in comparison with fine-grained aquifers. This in turn reduces chemical reaction between the two.

Most of the aquifer matrix is composed of rock classified as either highly organic marlstone or low-grade oil shale. The principal minerals are quartz and calcium and magnesium carbonates. Some feldspar and clay (illite) are also present. Kerogen, like most petroleum minerals, is hydrophobic and would further inhibit contact between aquifer water and the mineral matrix. However, it might promote adsorption of organic pollutants.

The Environmental Baseline Report (WRSP, 1976b) does not state whether pH measurements of sample water were performed in the field or the laboratory. The highly erratic sequences reported indicate the latter. It is evident that the water is basic, probably near pH 8. The Eh has never been reported; however, in general, reducing conditions exist in confined aquifers due to lack of oxygen. The presence of iron sulfide nodules near the contact of the Uinta and Green River Formations indicates reduction of sulfates, which supports the concept of reducing conditions within the aquifer.

Macroinorganics

The heavily predominant cation in the shale pile leachate is sodium, which is very mobile. Sodium is also the predominant cation in the aquifer water. This is due to the dissolution of nahcolite ($NaHCO_3$) modules. The present high concentrations of sodium indicate that little attenuation would occur. If attenuation did occur, it would probably be due to precipitation of nahcolite, or to dilution by aquifer water of lower sodium concentration.

The other major cation in the leachate is calcium. Again, this ion is common in the water of the Bird's Nest Aquifer. The most likely attenuation mechanism would be precipitation of calcite. Leachate concentrations are too high to use Debye-Hickel theory to predict precipitation.

The predominant anion is sulfate. The moderate solubility of gypsum could lead to the precipitation of sulfate as calcium sulfate. If conditions were sufficiently reducing, the sulfate might be converted to sulfide and immobilized by iron or other heavy metals.

The major anion in the aquifer water beneath the proposed processed shale pile is bicarbonate. Precipitation of this ion as both nahcolite and calcite has already been discussed. Dilution, again, may play a major role in attenuation.

Trace Elements

Arsenic is one of the trace elements of prime concern, due to both leaching from the shale pile and disposal of arsenic-impregnated wastes. The major attenuation mechanism is adsorption onto clays, which is unlikely to be important in the Bird's Nest Aquifer due to the small clay content and small surface contact. However, reduction of sulfate to sulfide might result in the precipitation of the arsenic sulfide minerals orpiment or realgar.

Selenium and zinc are both quite mobile and attenuation mechanisms are few. Strongly reducing conditions might lead to reduced mobility of both elements. Reduced selenium might form insoluble minerals with heavy metals. Zinc might precipitate in combination with sulfide as sphalerite.

The mobility of both fluoride and strontium may be limited by precipitation. Sufficient excess calcium in the leachate may precipitate the fluoride as fluorite. The strontium may be precipitated by either bicarbonate or sulfate.

Organics

The high pH of aquifer water rules out the precipitation of organics mentioned in Section 8. However, the kerogen contained in the walls of the solution cavities may prove effective in adsorbing complex and possibly carcinogenic compounds. The small area of surface contact would tend to limit this sorption. As the effectiveness of kerogen as an adsorbent has never been tested, its importance cannot be estimated with confidence at this time. This is true with regard to both quantitative (i.e., how much is adsorbed) and qualitative (i.e., what organic components are adsorbed) adsorption characteristics.

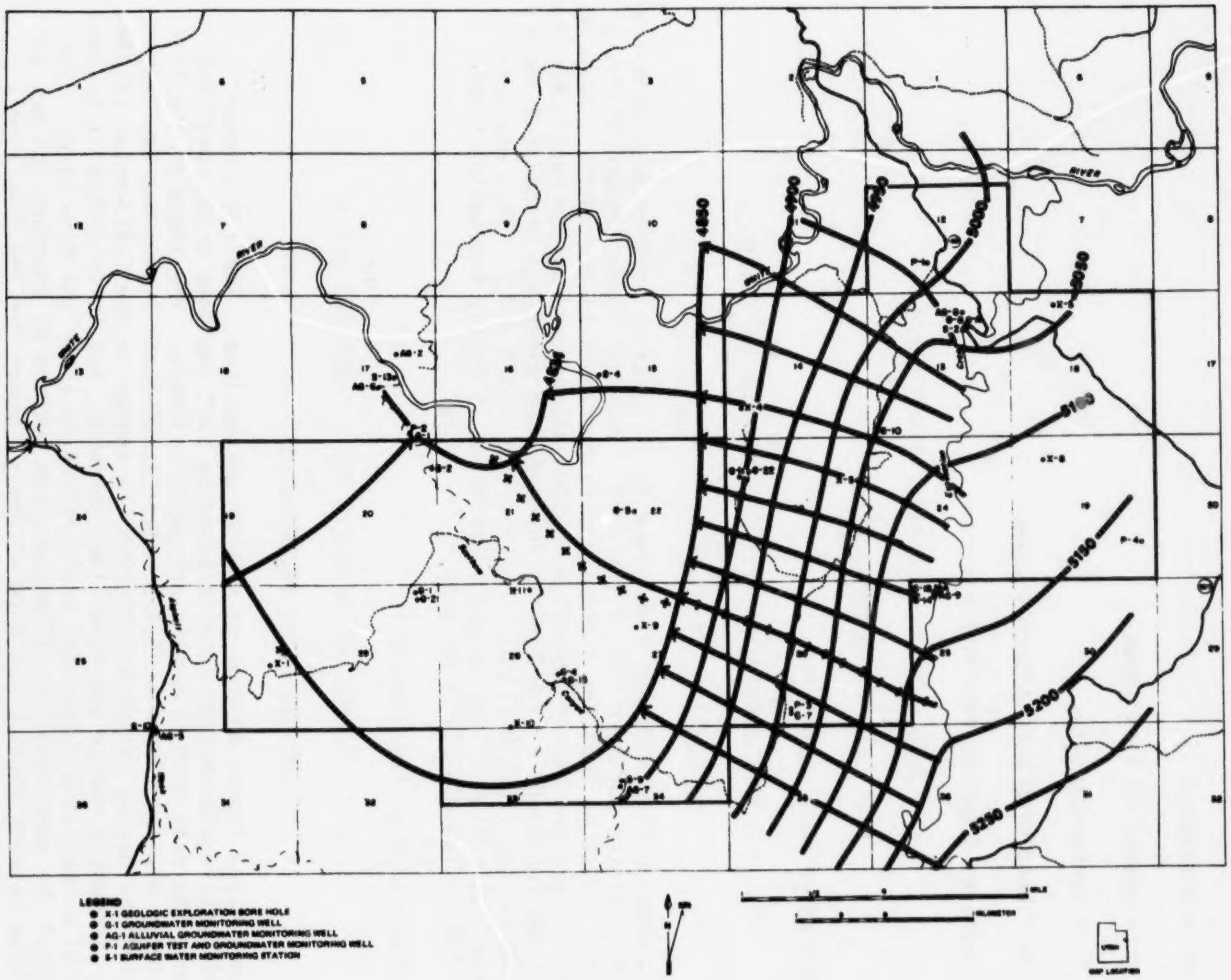
POLLUTANT MOVEMENT

One of the major uncertainties involves the flux of possible pollutants. Calculations in Section 7 indicate that under present plans for operation of the waste shale dump and present climatic conditions, little infiltration of water and resultant leaching will occur. It is impossible to assign specific figures to concentration and flux of possible pollutants. However, this uncertainty does not render an analysis of the flow and change of concentration of possible pollutants useless, for changing disposal procedures could result in shale pile leachate production. Unforeseen accidents or design faults could cause pollutant spills or sources of pollution such as leakage through waste water holding pond sealers. Long-term considerations include climatic factors.

Evaluation of flow in the Bird's Nest Aquifer beneath oil shale Tracts U-a and U-b is complicated by the nonhomogeneous hydraulic and water quality characteristics present. In an effort to create a workable model of the aquifer, it has been divided into four units, indicated in Figure 9-1. The crosses in the figure represent the boundary between the high and the low salinity portions of the aquifer. Unit A comprises the southeast section of the aquifer. The transmissivity, calculated from tests at well P-3, is about 0.007 liters per second per meter (50 gallons per day per foot). Salinity is relatively low, the total dissolved solids concentration averaging below 2,000 mg/l. Unit B is the northeast section, west of Evacuation Creek. This is the high salinity portion of the aquifer, with TDS levels varying between 3,000 and 4,500 mg/l. The transmissivity at well P-1 is about 0.2 liters per second per meter (1,500 gallons per day per foot). Unit C, the southwest portion, is the high transmissivity, low salinity area. TDS levels are below 2,000 mg/l and the transmissivity is about 9.3 liters per second per meter (70,000 gallons per day per foot). The entire proposed spent shale dump area is located above this portion of the aquifer. Finally, Unit D possesses high transmissivity and high salinity. The dissolved solids range from 2,000 to 4,000 mg/l. Transmissivity values taken from well P-2 are used for both Units C and D. The proposed process area will be above Unit D.

The use of a flow net analysis assumes that the groundwater flow within an aquifer follows Darcy's law and that the transmissivity is constant over each grid area. Although this assumption is not strictly valid for this particular system, the system has been simplified in order to allow analysis.

When examining the flow net shown on Figure 9-1, it should be kept in mind that different areas have different T values and thus the net cannot be interpreted in the normal manner. The head drop across each square of Units A and B is 50 feet; the drop across the squares of Units C and D is 16 feet.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LEGEND
● X-1 GEOLOGIC EXPLORATION BORE HOLE
● G-1 GROUNDWATER MONITORING WELL
● AG-1 ALLUVIAL GROUNDWATER MONITORING WELL
● P-1 AQUIFER TEST AND GROUNDWATER MONITORING WELL
● S-1 SURFACE WATER MONITORING STATION
RIVER
MAP LOCATION

Figure 9-1. Flow net for Bird's Nest Aquifer.

Discharge can be calculated with the formula:

$$Q = nT\,\Delta h\ ,$$

where

Q = discharge

n = number of flow tubes

T = transmissivity

Δh = head drop across each square.

The discharge from aquifer Unit A is:

$$Q = 3(50\ \text{gal/d/ft})(50\ \text{ft}) = 7{,}500\ \text{gal/d}$$

$$= 1{,}003\ \text{ft}^3\text{/d}\ (28.3\ \text{m}^3\text{/d})$$

The discharge from Unit B is:

$$Q = 7(1{,}500\ \text{gal/d/ft})(50\ \text{ft}) = 525{,}000\ \text{gal/d}$$

$$= 70{,}193\ \text{ft}^3\text{/d}\ (1{,}983\ \text{m}^3\text{/d})$$

This discharge figure may be high since it is based on aquifer test data from well P-1, at the northern end of the area. The much lower transmissivity at well P-3 indicates that the transmissivity decreases to the south. Therefore, the 0.2 liters per second per meter (1,500 gallons per day per foot) used for Unit B may represent a high limit. The combined discharge of Units A and B is 2,000 m^3/day (70,000 ft^3/d), equivalent to 0.824 ft^3/s. This would seem to be a little high if the source of recharge is really Evacuation Creek, which has a flow of 1 ft^3/s or less.

The discharge from Unit C is:

$$Q = 1(70{,}000\ \text{gal/d/ft})(16\ \text{ft}) = 1{,}120{,}000\ \text{gal/d}$$

$$= 150{,}000\ \text{ft}^3\text{/d}\ (4{,}200\ \text{m}^3\text{/d})$$

This discharge figure depends on several assumptions. The 1,473-meter (4,834-foot) equipotential line is based on just one data point, well P-2. However, the data from this well are quite reliable. The shape of the line was simply mirrored from the 1,478-meter (4,850-foot) line above it. The actual shape may be somewhat different. A change in the 1,473-meter (4,834-foot) line would change the flow lines somewhat, but it is difficult to conceive of a realistic shape that would radically alter the flow lines. The fact that the water quality difference (see Section 6) boundary follows the flow line between Units C and D is a strong support for the flow line's accuracy. A more serious difficulty is the actual head difference in the high transmissivity portion of the aquifer. The figure of 4.9 meters (16 feet) is taken from the difference between the last 50-foot line and the P-2 well elevation. In fact, an examination of the water level data (see Figure 9-1) indicates that the difference is probably somewhat less. Unfortunately, water level data do not exist for wells in this area, so the exact difference cannot be ascertained. The map indicates that 3.1 meters (10 feet) is approximately correct. The discharge thus would be

$$Q = 1(70{,}000 \text{ gal/d/ft})(10 \text{ ft}) = 700{,}000 \text{ gal/d}$$

$$\doteq 94{,}000 \text{ ft}^3\text{/d } (2{,}600 \text{ m}^3\text{/d})$$

A discrepancy is immediately apparent. According to the flow net, the inflow to Unit C is 1,000 ft^3/d (30 m^3/d) while the discharge from it is 94,000 ft^3/d. A deficit of 93,000 ft^3/d (2,600 m^3/d) exists. Even if the Unit C flow net "square" is so incorrect that all of the recharge from the Evacuation Creek area should enter the Unit C square, the deficit would still be 22,000 ft^3/d (600 m^3/d). Some of this difference may be made up by recharge from the alluvium of Asphalt Wash. Neither T values nor water levels are available from this area. Even so, the volume of recharge is estimated to be small, due to the absence of any perennial water course in the canyon and the lack of a large drainage area. Two possible further sources of recharge exist: upward leakage from lower aquifers and downward leakage from the White River. Downward leakage is more likely, because upward leakage into the Bird's Nest Aquifer would have to penetrate the Mahogany oil shale zone and because low water temperatures have been measured at well P-2, indicative of surface recharge (see Section 6).

In summary, Unit A discharges about 1,000 ft^3/d (30 m^3/d), Unit B about 70,000 ft^3/d (2,000 m^3/d), and Units C and D each about 90,000 ft^3/d (2,500 m^3/d). This leaves a discrepancy of 20,000 to 90,000 ft^3/d (500 to 2,500 m^3/d) in Units C and D, probably made up by downward leakage from the White River. The small data base must be kept in mind when evaluating these conclusions.

Although these figures are very rough, they do have some significance for evaluating possible dilution of pollutants. The total daily discharge of the area under the proposed spent shale pile is only 90,000 ft^3 (2,500 m^3) or about 1.1 ft^3/s. Thus the continuous inflow from a pollution source of 1 ft^3/s would equal the natural discharge. Although this calculation seems to indicate that very little dilution would take place, there is a large volume of water in the aquifer to mix with possible pollutants. The total volume of water is given by:

$$V = Amp,$$

where

V = volume

A = area

m = saturated thickness

p = porosity.

If Unit C covers about 5.5 square miles and the aquifer is 130 feet thick with a porosity of 7 percent, then

$$V = 5.5\ (5{,}280\ \text{ft})^2\ (130\ \text{ft})\ (0.07)$$

$$= 1.4\ \text{billion ft}^3\ (39\ \text{million m}^3)$$

or about 32,000 acre-feet. This is about 16,000 times the volume introduced daily by an inflow of 1 ft^3/s.

The "mixing" referred to in this discussion is due to hydrodynamic dispersion of pollutants which occurs in groundwater. This dispersion results on a microscopic scale from nonuniform velocity distributions resulting from tortuous water flow in the porous medium of the aquifer. On a macroscopic scale, dispersion results from heterogeneities in the spatial distribution of aquifer permeability, causing flow lines to deviate, converge, or diverge. Molecular diffusion also contributes to the overall dispersive action. The result of these processes is longitudinal and lateral spreading of a pollutant within the groundwater body. Although these mechanical and physiochemical processes are analogous to the commonly observed atmospheric mixing of smoke from a smoke stack or turbulent mixing in surface waters, the rates of these processes are much reduced in groundwater systems.

Both flow rate and flow pattern profoundly affect possible dilution. From the storage/discharge ratio, it is obvious that the flow rate is moderate. Using the formula

$$v = Q/Lmp\ ,$$

where

v = groundwater velocity

Q = discharge

L = length of area along which discharge is occurring

m = thickness of aquifer

p = porosity,

the groundwater velocity is

$$v = (90{,}000\ \text{ft}^3/\text{d})/(5{,}280\ \text{ft})(130\ \text{ft})(0.07)$$

$$= 1.9\ \text{ft/d} = \text{about } 700\ \text{ft/y}\ (213.5\ \text{m/y})$$

Increasing the recharge rate by pollution inflow would eventually increase the outflow and thus the flow rate. Faster mixing could be expected at higher flow rates. The flow rates discussed refer to the northern boundary of Unit C, and the average flow rate would be much slower, perhaps one-half the calculated velocity.

The flow pattern would not encourage dilution of pollutants in the aquifer. From the configuration of the flow lines in Figure 9-1, it may be seen that even a wide, diffuse source of pollution in either Units C or D could be expected to form a relatively long, narrow plume extending northwest. Such a pattern would concentrate the pollutant, restricting the contact area with aquifer water. The increase in velocity accompanying the concentration would enhance mixing within the restricted zone of contact.

SATURATED FLOW ALTERNATIVES

An alternative to the penetration of pollutants into the Bird's Nest Aquifer should be considered. Due to the numerous claystone layers within the Uinta Formation and the marlstone Green River Formation above the Bird's Nest Aquifer, pollutants are likely to form perching saturated layers above the Bird's Nest Zone. The regional structure would cause the water to flow down to the northwest. If the clay beds along which the pollutants were flowing were deep in the section, the pollutants would pass beneath the White River and probably eventually be dissipated within the Uinta Formation. If the perching beds were higher, the pollutants would flow into the alluvium of the White River valley and thus eventually into the river. The presence of evaporite deposits on sheltered outcrops of the claystone beds of the Uinta Formation indicates that infiltration and movement of moisture along these beds is occurring at the present time.

Since no saturated zones within the Uinta Formation have been found or investigated, little can be stated on the effects of existing water chemistry. The major difference in the Uinta Formation relative to the Bird's Nest Aquifer is that the water would be flowing through bedding planes and partings in clay beds. Intimate contact with a large surface area of clay would result. The major effects on pollutant attenuation would be an increase in attenuation of arsenic and zinc due to adsorption.

Little hydrologic analysis of the White River alluvium has been performed. From soil analyses it seems similar to the soil beneath the proposed spent shale pile in clay content. Thus the effects of movement through it probably would be similar to those discussed in Section 8. Strongly reducing conditions are unlikely in the highly permeable portions of the shallow, unconfined aquifer. However, alluvial clay deposits may become anaerobic and reduced. Considerable dilution might occur. The pollutants probably would move slowly downstream through the alluvium, mixing with better quality water as they moved. They would eventually be removed from the aquifer by slow discharge into the river during the low flow periods. The mass of this loading and thus the effects on water quality cannot be estimated with certainty.

SECTION 10

PRIORITY RANKING OF SOURCES AND CAUSES

PRIORITY RANKING SCHEME

In the preceding sections, proposed oil shale operations on Federal Lease Tracts U-a and U-b have been described. These descriptions have identified potential pollution sources, methods of waste disposal, and potential pollutants associated with the various sources, and an evaluation of the infiltration and subsequent mobility of these pollutants has been provided. These descriptions and assessments allow the prioritization or ranking of sources and pollutants presented in this section.

Three basic criteria have been used to develop the source-pollutant ranking. The first criterion ranks these items relative to volume of waste, persistence, toxicity, and concentration. Certainly the source with the largest waste volume with pollutants of longest persistence, highest toxicity, and highest concentration will receive the highest priority for monitoring.

The second ranking criterion is based on the mobility of pollutants. Mobility is a function of method of disposal, waste loading, and sorptive and chemical interactions. The most mobile pollutants will receive the highest priority or ranking.

The third criterion in the ranking scheme addresses the known or anticipated harm to water use. This is a function of the existing or potential magnitude of various water uses and the concentration changes which may result from contamination.

FIRST-CRITERION RANKING

Basic data on potential pollutant sources and causes and potential pollutants are provided in Table 10-1. The data on waste loads address Phase IV or full commercial operation. More detailed information is presented in Sections 2 and 3. Information in Table 10-1 indicates the following partial ranking with regard to size (i.e, volume of waste) of the potential sources and causes.

TABLE 10-1. SUMMARY OF POTENTIAL POLLUTANT SOURCES AND CAUSES

Pollution source or cause	Disposal methods	Potential pollutants	Possible concentration	Volume of waste^{a}
Solid wastes				
Surface disturbance	Some stockpiles, revegetation use	Salts-$CaSO_4$	Uncertain	400 acres total disturbed
Construction debris	Landfill	Nitrates Sulfides Trace metals	Uncertain	17 t/d^{d} maximum
Raw oil shale	Stockpiled or placed on spent shale pile	-See discussion of spent shale^{b}-		240 t/d^{d} dust and 168,000 t/d^{d} mined
Spent oil shale	Pile in Southam Canyon	Major inorganics^{c}:	(mg/l)	
		TDS	140,000	100,000 t/d^{d} spent shale produced; 6,000-20,000 ppm soluble; thus 600-2,000 t/d soluble material produced
		Sodium	35,000	
		Calcium	3,000	
		Magnesium	4,700	
		Potassium	600	
		Sulfates	90,000	
		Chlorides	3,000	
		Fluoride	17	
		Trace elements:	(mg/l)	
		Mercury	0.005	
		Lead	0.004	
		Cadmium	0.006	
		Arsenic	0.2	
		Copper	0.2	
		Zinc	3	
		Selenium	2	
		Iron	2	
		Boron	10	
		Organics:		
		Oil and grease	Unknown	Unknown
		Phenols	Unknown	Unknown
		TOC	3 to 5 percent by weight	1,000-5,000 t/d^{d}
		Benzene extracts (POM, PAH)	2,500 ppm possibly	200 t/d^{d} possibly
		Carcinogens	Unknown	Unknown

(continued)

TABLE 10-1 (continued)

Pollution source or cause	Disposal methods	Potential pollutants	Possible concentration	Volume of waste[a]
Sulfur byproducts	Sale or disposal in spent shale pile	Sulfur compounds	50 percent elemental S	85 t/d[d] (dry)
Oil upgrading catalysts:	Spent shale pile (landfill) or recycle		Unknown: solubility characteristics of spent catalysts unknown	
HDN (naphtha, hydrotreater)		Nickel, arsenic		1,300 t/y
Miscellaneous catalysts		Iron, copper, nickel, zinc oxides and sulfides, cobalt molybdate		325 t/y
Spent filters (carbon and diatomaceous earth)		Adsorbed hydrocarbons	Unknown; nature and solubility of these organics uncertain	136 t/y
Miscellaneous Landfill (garbage, etc.)	Landfilled or put in spent shale pile	Nutrients Sulfides Organics	Uncertain	3 t/d[d] (dry); 300 t/d[d] (wet)
Sewage sludge	Soil amendment for revegetation	Organics Nutrients	Uncertain	2.5 t/d[d] (wet); 0.5 t/d[d] (dry)
Water treatment plant sludges	Spent shale disposal pile	TDS	Uncertain	3 t/d[d] (dry); 300 t/d[d] (wet)
Liquid wastes			(mg/l)	
Retort water	Moisten spent shale; some recycled via sour water stripper	Bicarbonate	500-31,000	80 gpm production rate
		Carbonate	500-30,000	
		Chloride	0-1,300	
		Arsenic	0-1	
		Nitrate	<1-330	
		Ammonia	10-13,000	
		Phenols	42-390	
		TOC	15,000-20,000	
		Carboxylic acids	Up to 6,000	
		Amines	Up to 1,600	
		BOD_5	Up to 27,100	
		POM's, etc.	Unknown	
		Phosphates	15	
		Sulfides	1,200	
		TDS	>15,000	

(continued)

TABLE 10-1 (continued)

Pollution source or cause	Disposal methods	Potential pollutants	Possible concentration	Volume of waste[a]
Sour water stripper	~2/3 reused in hydrotreating; 1/3 to plant sewers and use in dust control, spent shale moisturizing	Ammonia Phenols COD Oil and grease	(mg/l) 25-50 80-150 500-1,500 50-100	1,250 gpm
High TDS waste water	Tank storage, use in dust control and spent shale moisturizing	TDS	5,000-10,000 mg/l	775 gpm
Oily waste water stream	Oils reclaimed	Oil and grease	Unknown	30 t/d[d] (wet)
Sanitary waste water	Moisten spent shale pile; dust control (after treatment)	Nitrates Ammonia Phosphates TDS Organics	(mg/l) 10-20 15-20 5-10 800-1,000	45 gpm
Storm water runoff	Holding pond; moisten spent shale	Miscellaneous inorganics (Ca, Na, HCO_3, SO_4) Oils and grease	Highly variable	Variable with time: maximum design 45 acre-feet (100 y storm)
Mine water	Dust control in mine; moisturize spent shale	Nitrates (explosives) Soluble materials (Bird's Nest or Douglas Creek aquifers)	Explosive residues—unknown See Existing Water Quality for aquifers (Section VI)	Unknown
Explosive residues	-See mine water discussion-		Unknown	Unknown
Catastrophic failures (tankage failure)	Materials held by dikes around tanks; cleanup plan not defined	Naphtha High TDS wastes Fuel oil Ammonia Diesel fuel Pour-point depressers	Uncertain	350,000 bbl 220,000 bbl 70,000 bbl 50,000 bbl 35,000 bbl

[a] Phase IV unless otherwise stated

[b] Levels for raw shale probably lower than those listed for spent shale

[c] High levels for spent shale leachate

[d] tons/day

- Solid waste sources

  1. Spent shale
  2. Sulfur byproducts
  3. Spent catalysts
  4. Miscellaneous landfill trash, etc.
  5. Water treatment plant sludges
  6. Sewage sludge
  7. Spent filters
  8. Surface disturbance.

- Liquid waste sources

  1. High TDS waste water
  2. Sour water stripper wastes
  3. Retort water
  4. Storm water runoff
  5. Oily waste water
  6. Mine water
  7. Sanitary waste water.

This listing provides a general ordering with regard to waste volume rather than a strict ranking. For example, over a short period, storm water runoff can be the largest liquid waste stream but, in general, will be small. Mine water discharges are assumed to be small at this time but are, to some extent, an unknown.

A second general ranking under the first criterion can be developed based on the concentration of potential releases and on their possible toxicity. This partial ranking is as follows:

- Solid waste sources

  1. Spent shale (TDS, Na, SO_4, trace metals, organics)
  2. Spent catalysts (Ni, As, Cu, Zn, Co, Mo, etc.)
  3. Spent filters (organics, As)
  4. Water treatment plant sludges (TDS)
  5. Miscellaneous landfill (organics, sulfides)
  6. Sewage sludge (nutrients, organics)
  7. Sulfur byproducts (sulfur compounds)
  8. Surface disturbance (Ca salts).

- Liquid waste sources

  1. Retort water (TDS, trace metals, organics)
  2. Sour water (phenols, ammonia, organics)
  3. High TDS waste water (TDS)
  4. Storm water runoff (salts, organics)
  5. Oily waste water (organics)
  6. Mine water (salts, oil and grease)
  7. Sanitary waste water (nutrients, organics).

Combining the results of these two partial rankings provides a preliminary first-criterion ranking. Solid waste sources may be grouped into three categories:

- Solid waste sources
  - Highest priority: spent shale, spent catalysts
  - Intermediate priority: water treatment plant sludges, miscellaneous landfill materials, sulfur byproducts, and spent filters
  - Lowest priority: sewage sludges, surface disturbance.

Similarly, liquid waste sources may be grouped as follows:

- Liquid waste sources
  - Highest priority: high TDS waste water, sour water, retort water
  - Intermediate priority: storm water runoff, oily waste water
  - Lowest priority: mine water, sanitary waste water.

SECOND-CRITERION RANKING

The second-criterion ranking calls for setting priorities based on the mobility of the potential pollutants which have been identified. Table 10-2 presents a brief summarization of the pollutant mobility information provided in Sections 7 through 9. Because of the nature of the waste disposal plans for Tracts U-a and U-b (Table 10-1; see Section 2) for the mobility evaluations, the sources have been lumped into source areas. Thus, for example, the discussion of the spent shale disposal area takes into account the mobility of pollutants from a variety of solid sources to be deposited in the spent shale pile and on a variety of liquid wastes to be used to moisturize the spent shale (Table 10-2).

TABLE 10-2. SUMMARY OF INFILTRATION AND MOBILITY EVALUATIONS PRESENTED IN SECTIONS 7 THROUGH 9

Source area	Infiltration potential	Potential pollutants	Mobility in vadose zone	Mobility in saturated zone	
Spent shale disposal and landfill: spent shale leachate construction material trash and garbage spent catalysts spent filters elemental sulfur spent shale raw shale dust water treatment sludge miscellaneous effluent and storm water discharges	Infiltration potential low during construction Probably increased during leaching and water harvesting phases, but chance of deep percolation is limited	Major macro-inorganics:		Bird's Nest Aquifer:	Perched aquifers in Uinta:
		TDS	Little attenuation	Attention low for macro-organics; possibly some precipitation	Attenuation low for macroinorganics; possibly some precipitation
		Ca	Some $CaCO_3$ and $CaSO_4$ precipitation		
		Mg	Some $MgCO_3$ precipitation		
		Na	Little attenuation		
		SO_4	Some $CaSO_4$ precipitation		
		Cl	Little attenuation		
		F	Precipitated as CaF_2		
		Trace metals:			
		As	High mobility	Trace metal precipitation as sulfides and bicarbonates expected	Some trace metal precipitation, adsorption on clays of bedding planes
		Sr	Probably limited mobility		
		Se	High mobility		
		Zn	Moderate mobility		
		Cu	Low mobility		
		Ni	Moderate mobiltiy		
		Co	Probably precipitated		
		Mo	High mobility		
		Pb	Low mobility		
		B	Possibly moderate mobility		
		Organics	Some adsorbed Some mobile at high TDS	Some adsorption; little precipitation expected	Some adsorption on clays
		Micro-organisms	Removed by adsorption and filtration	Little effect expected	Adsorption expected

(continued)

TABLE 10-2 (continued)

Source area	Infiltration potential	Potential pollutants	Mobility in vadose zone	Mobility in saturated zone	
Process area: stockpiled soils treated effluent holding pond tankage area raw shale storm water runoff miscellaneous process wastes	Infiltration restricted due to shallow soils, steep slopes, exposed rock Infiltration greater in alluvial channels Infiltration through holding pond and water reservoir possible depending on seal	Major macro-inorganics: TDS Ca Na HCO_3 SO_4 Ammonia	Little attenuation in soils (e.g., low CEC) Some precipitation Some perching layers may develop in soils and in Uinta Formation	Bird's Nest Aquifer: Attenuation low for inorganics probably Some precipitation expected Mobility and chemical reactions for N species uncertain	Perched aquifers in Uinta: Attenuation low Precipitation of carbonates and sulfates probable
		Trace metals	Some precipitation expected	Some precipitation and adsorption expected	Some precipitation and adsorption
		Organics: Phenols Naphtha Miscellaneous fuels Oil additives Oil and grease Miscellaneous organics	Same as for spent shale disposal in general Mobility of fuels, naphtha, phenols largely unknown	Some adsorption will occur Interaction with microorganisms uncertain	Adsorption possible Biological interactions unclear
		Micro-organisms	Mobility limited	Mobility in cracks and fissures but adsorption, filtration continue	Attenuated by adsorption and filtration
Retention dams	Low in infiltration potential; soils with small storage capacity Some seepage into dams may occur, possibly into downstream alluvium (with moderately high infiltration potential Movement in cracks in Uinta if seal fails	Similar to those listed for spent shale disposal area; leachate and runoff water to be collected	Same as for spent shale disposal area	Bird's Nest Aquifer:	Perched aquifers in Uinta:
General features of source areas			Soils largely shallow and on steep slopes. Thus interaction low. Movement in Uinta Formation is in cracks, fissures, etc.	Dilution in Bird's Nest Aquifer not encouraged Mobility affected by compression strain related to subsidence	Movement enhanced by White River Dam and subsidence (if occurs) Movement may be into White River alluvium or beneath river into Uinta Formation

Three source areas are evaluated in Sections 7 through 9. These are: the spent shale disposal area, the process area, and the Southam Canyon retention dams. Most of the highest priority pollutants (based on the first-criterion ranking) are associated with the spent shale pile and the retention dams associated with this disposal area. Based on Table 10-2, the following categorization was developed:

- Spent shale disposal area
  - High mobility: TDS, sodium, sulfate, chloride, trace metals (arsenic, selenium, molybdenum), organics (PAH)
  - Moderate mobility: calcium, magnesium, fluoride, trace metals (zinc, nickel, mercury, cadmium, and possibly boron), some organics (phenols, organic acids, organic nitrogen compounds)
  - Low mobility: strontium, copper, cobalt, lead, some organics, microorganisms.

These data provide second-criterion ranking of potential pollutants. Mobilities may also be enhanced by the proposed reservoir behind the White River dam and by formation of fissures associated with subsidence stress. Because of their influence on the mobility of many constituents, water quality measures such as pH and Eh may be important measures for monitoring purposes.

THIRD-CRITERION RANKING

The third-criterion ranking addresses potential harm to existing or potential water users. As outlined in Section 4, use of groundwater which flows under Tracts U-a and U-b is largely limited to stock watering and possibly agriculture. Limitations on present use of water in the Bird's Nest Aquifer and the Douglas Creek Aquifer result largely from water quality (see Section 6) and depth (see Section 5) considerations and availability of surface water sources in the region. Potential future changes in availability and allocation of surface waters could appreciably alter the present perspective on depth-quality restriction.

In addition, some potential exists for mobility within the Uinta Formation and associated alluvial materials. By these routes, pollutants may enter the White River alluvium and eventually be discharged into the White River. The consequences of these releases (e.g., of high TDS wastes, organics, etc.) on downstream agricultural and municipal users are difficult to describe because of the uncertainties associated with estimating release rates. For this preliminary assessment, the concentration-toxicity ranking developed for the first criterion expresses the possible hazards to potential water users.

SUMMARY—PRELIMINARY PRIORITY RANKING

From the preceding discussion, a preliminary ranking of potential pollution sources and causes and potential pollutants can be developed. This result of the first pass through the monitoring methodology is termed the Level-One Ranking (see Section 1).

A great deal of effort has been expended on the study of the hydrogeology of the study area and a large amount of research has been conducted on oil shale development and environmental effects. However, significant information voids exist with regard to potential pollutant characterization and the mobility of these materials in the hydrosphere. Hence, professional judgment plays a large role in proposing the preliminary source-pollutant ranking shown in Table 10-3.

This ranking will serve as the basis for the design of a monitoring plan of the Tracts U-a and U-b oil shale development. The next phase of the design program includes evaluation of existing monitoring programs, identification of alternative monitoring approaches to address the source-pollutant ranking, and selection of a monitoring program for field implementation. This implementation will be used to verify (and quite probably revise) the preliminary ranking provided here.

TABLE 10-3. PRELIMINARY RANKING OF POLLUTANT SOURCES AND POLLUTANTS FOR OIL SHALE TRACTS U-a AND U-b

Source Area	Source priority ranking	Potential pollution source	Potential pollutant ranking		
			Highest	Intermediate	Lowest
Spent shale disposal area	Highest	Spent shale	TDS, Na, SO_4, As, Se, F, organics (PAH, carcinogens)	Ca, Mg, Zn, Cd, Hg, B, organics (phenols, etc.)	Pb, Cu, Fe
		High TDS waste water	TDS	---	---
		Sour water	Ammonia, phenols	Organics	---
		Retort water	As, Cl, S, organics (POM, carboxylic acids, phenols)	TDS, organics (amines, etc.)	Carbonates, PO_4, NO_3
		Spent catalysts	As, Mo	Zn, Ni	Fe, Cu, Co
	Intermediate	Stormwater runoff	TDS, organics, As, Se	Na, Ca, SO_4, HCO_3, organics	Zn, Cd, Hg
		Water treatment plant sludges	TDS	Major macroinorganics	Trace metals
		Miscellaneous landfill materials	Sulfides, organics	Sulfides	---
		Sulfur byproducts	Sulfides, sulfates	---	---
		Oily waste waters	Organics	Trace metals	---
		Spent filters	Organics, As	Trace metals	---
	Lowest	Sewage Sludge	Organics	Nutrients	---
		Mine water	TDS, oil and grease	Trace metals, organics	Macroinorganics
		Sanitary waste water	Organics	Nutrients	Macroinorganics
		Surface disturbance	Calcium salts, TDS	Macroinorganics	---
Process area	Highest	Effluent holding pond	TDS, organics	Trace metals, nutrients	---
		Raw shale	TDS, As, Se, organics	Macroinorganics	Trace metals
		Tankage area	Miscellaneous fuels, oil additives, ammonia, TDS	---	---
	Intermediate	Storm water runoff	TDS, organics	Macroinorganics	---
		Miscellaneous process waste streams	TDS, organics, ammonia	Macroinorganics, trace metals	Nutrients
	Lowest	Surface disturbance	Calcium salts, TDS	Macroinorganics	---
Retention dams	(Sources same as spent shale disposal area.)		TDS, organics (PAH, carcinogens, phenols, etc., As, Se, Mo, ammonia, Na, SO_4	Ca, Mg, Zn, Ni, Cd, Hg, other organics	Pb, Cu, Fe, nutrients

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APPENDIX A

THE WATER BALANCE METHOD

For the purposes of this report, the water balance equation is written as

$$S = (P - PET) - R/o - \Delta ST \quad ,$$

where

S = moisture surplus
P = precipitation
PET = potential evapotranspiration
R/o = runoff
ΔST = change in storage (see Figure A-1)

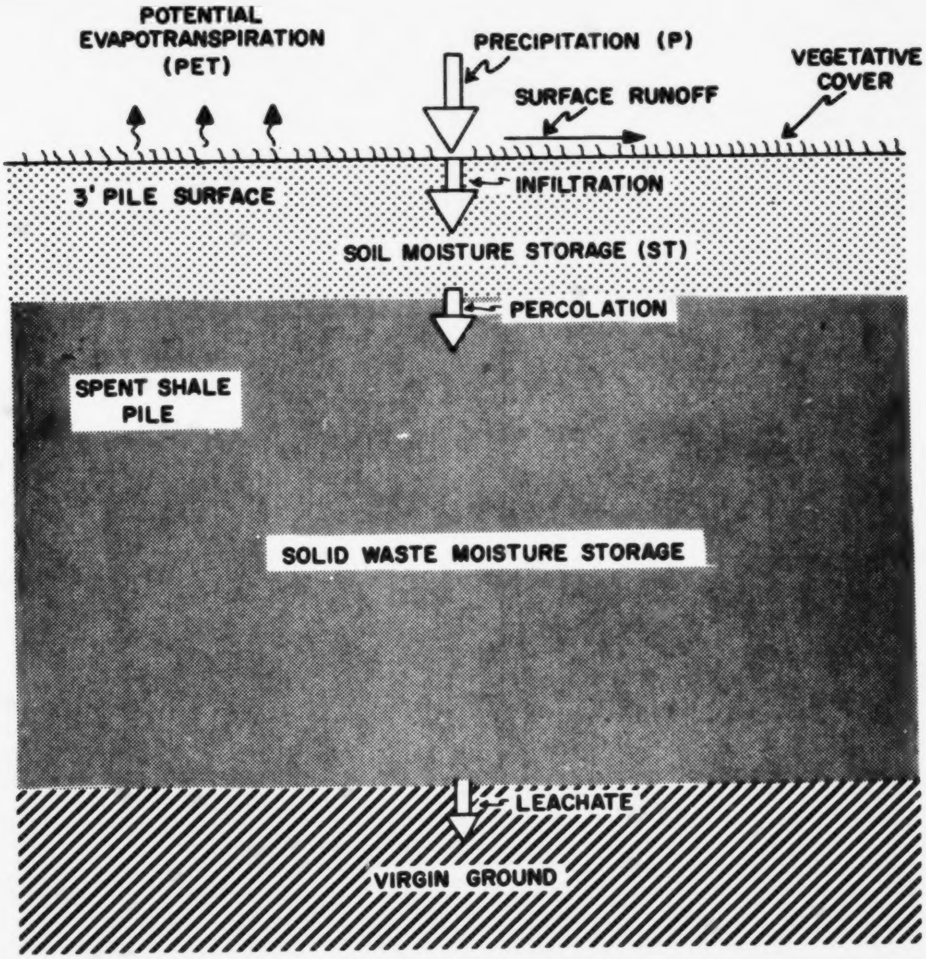
POTENTIAL EVAPOTRANSPIRATION (PET)
PRECIPITATION (P)
VEGETATIVE COVER
SURFACE RUNOFF
3' PILE SURFACE
INFILTRATION
SOIL MOISTURE STORAGE (ST)
PERCOLATION
SPENT SHALE PILE
SOLID WASTE MOISTURE STORAGE
LEACHATE
VIRGIN GROUND

Figure A-1. Schematic drawing showing components of water balance evaluation.

Assuming R/o is essentially zero throughout the year on the oil shale tract, the equation reduces to

$$S = (P - PET) - \Delta ST \quad .$$

Fenn, Hanley, and DeGeare (1975) write the equation slightly differently:

$$S = (P - AET) - R/o - \Delta ST \quad ,$$

where

AET = actual evapotranspiration

The differences will be explained later.

As pointed out in Section 7, the water balance method developed by Thornthwaite and Mather (1957) is simply a bookkeeping procedure to account for soil-water surplus or deficiencies. The first line in the water balance table (see Table 7-2) lists the monthly temperatures in degrees Fahrenheit. The temperatures for the oil shale tract were adjusted from data at the Vernal Airport.

The second line in the table represents potential evapotranspiration, PET, which was calculated for each month by the Blaney-Criddle equation (Schultz, 1973):

$$PET = KF \quad ,$$

where

K = crop-use coefficient

F = consumptive-use factor

= sum of monthly consumptive-use factors for each month during the growing season = $\frac{\Sigma td}{100}$

t = mean monthly temperature (degrees Fahrenheit)

d = percentage of annual daytime hours during each month

For the oil shale tract, the crop-use factor was assumed to be 0.70 for sparse, native vegetation receiving only precipitation (Schultz, 1973). For months with mean temperatures below 32° F, it is assumed that precipitation falls as snow. Thornthwaite and Mather (1957) indicated a procedure for accommodating snow melt runoff during the months following those with temperatures below freezing. This procedure is discussed below.

The fourth line in the water budgets used in this report represents the monthly differences between precipitation and potential evapotranspiration (P - PET). For those months with negative values, soil water must be extracted from storage to accommodate evapotranspiration. Months with positive values represent periods when excess water, above storage requirements, is available for making up soil water deficits or for runoff and deep percolation.

The fifth line lists the monthly accumulated potential water losses,

$$\Sigma NEG (P - PET).$$

If the sum of the positive (P - PET) values exceeds the sum of the negative (P - PET) values, accumulated losses are initiated by placing a value of zero in the last column with a positive P - PET value (see Table 7-4). However, for dry conditions with storage less than the maximum or potential value, it is necessary to determine a value of potential water deficiency with which to start accumulating the negative values of (P - PET). The technique to determine the value is called the method of successive approximation. This method requires the use of a soil moisture retention table given by Thornthwaite and Mather (1957). For the oil shale tracts, it was determined that the "water-holding capacity" of the soils and spent shale is about 120 mm, reproduced as Table A-1. Note that this table shows the soil moisture retained for different amounts of potential evapotranspiration (PET).

The method of successive approximation involves the following algorithm:

1. Sum up the positive and negative values of (P - PET)
   a. If the sum is positive, the value of accumulated potential water loss at which to start accumulating negative values = 0
   b. If the sum is negative, use successive approximations. Go to Step 2.
2. Use appropriate soil moisture retention (SMR) (Table A-1)
3. Select the value of SMR = ΣNEG(P - PET) = SMR(1)
4. SMR(1) + ΣPOS(P - PET) = SMR(2)
5. Read PE on left-hand column corresponding to SMR(s) = PE(1)
6. PE(1) + ΣNEG(P - PET) = SMR(3)
7. SMR(3) + ΣPOS(P - PET) = SMR(4)
8. Repeat until no change occurs in the SMR estimate.

The method of successive approximations was used to determine the value -158 in Table 7-2. Note that after the initial value of ΣNEG(P - PET), subsequent values are obtained by adding (P - PET) values from the successive months.

The sixth row in the table, ST, is the amount of water in storage in the selected soil depth (1 meter). For months when ΣNEG(P - PET) values are zero, ST values may be (1) equal to maximum storage, or (2) some lesser value representing deficiencies for previous dry months. For the latter case, successive months with zero values of ΣNEG(P - PET) will increase soil water to maximum storage. For months where ΣNEG(P - PET) values are negative, storage values are found from the related soil moisture retention Table A-1.

During months with temperatures below freezing, the assumption is that precipitation collects on the ground as snow and does not contribute to storage, runoff, or percolation. On successive months with temperatures above

TABLE A-1. SOIL MOISTURE RETENTION TABLE - 125 mm[a]

	Water retained in soil									
PET[b]	0	1	2	3	4	5	6	7	8	9
0	125	124	123	122	121	120	119	118	117	116
10	115	114	113	112	111	110	109	108	107	106
20	106	105	104	103	102	102	101	100	99	99
30	98	97	96	95	94	94	93	92	91	90
40	90	89	88	87	86	86	85	84	84	83
50	83	82	82	81	80	80	79	79	78	77
60	76	76	75	74	74	73	73	72	72	71
70	70	70	69	69	68	68	67	67	66	65
80	65	64	64	63	63	62	62	61	61	60
90	60	59	59	58	58	57	57	56	56	55
100	55	55	54	54	53	53	53	52	52	51
110	51	51	50	50	49	49	49	48	48	47
120	47	47	46	46	45	45	45	44	44	43
130	43	43	42	42	41	41	41	41	40	40
140	40	40	39	39	39	38	38	38	38	37
150	37	37	36	36	36	35	35	35	35	34
160	34	34	33	33	33	32	32	32	32	31
170	31	31	31	30	30	30	30	30	30	29
180	29	29	29	29	28	28	28	27	27	27
190	26	26	26	26	26	25	25	25	25	25
200	24	24	24	24	24	23	23	23	23	23
210	22	22	22	22	22	22	22	21	21	21
220	21	21	21	21	20	20	20	20	20	20
230	19	19	19	19	19	18	18	18	18	18
240	18	18	17	17	17	17	17	17	17	17
250	16	16	16	16	16	16	16	16	15	15
260	15	15	15	15	15	14	14	14	14	14
270	14	14	14	14	14	13	13	13	13	13
280	13	13	13	13	13	12	12	12	12	12
290	12	12	12	12	12	11	11	11	11	11
300	11	11	11	11	11	10	10	10	10	10
310	10	10	10	10	10	10	10	10	9	9
320	9	9	9	9	9	9	9	9	9	9
330	8	8	8	8	8	8	8	8	8	8
340	8	8	8	8	8	7	7	7	7	7

* * * * * * * * * * * * * * * * *

	0	5		0	5		0
350	7	7	450	3	3	550	1
360	7	6	460	3	3	560	1
370	6	6	470	3	3	570	1
380	6	5	480	2	2	580	1
390	5	5	490	2	2	590	1
400	5	5	500	2	2	600	1
410	4	4	510	2	2	610	1
420	4	4	520	2	2	620	1
430	4	4	530	2	2	630	1
440	3	3	540	2	1	640	1

[a] Thornthwaite and Mather, 1957.

[b] Potential evapotranspiration.

freezing, accumulated snow is added to the additional precipitation. For the cases examined in this report, accumulated snow generally was not sufficient to bring soil water storage up to the maximum.

The seventh line on the water balance table represents the change in storage between successive months.

The final row, S, represents surplus water available for either runoff or deep percolation. In this report we have assumed zero runoff, so surplus water is assumed to drain into the vadose zone. Note that surplus values are obtained only during those months that storage equals maximum SMR. Values in this row are calculated from the water balance equation. Fenn, Hanley, and DeGeare (1975) recommend using actual evapotranspiration (AET) rather than PET when soil water deficits reduce evapotranspiration rates, i.e., when AET is less than PET. In this report the method of Thornthwaite and Mather (1957), which does not account for SMR-AET relationships, has been strictly applied.

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☆ U.S. GPO:1979-684-270-2111